APPENDIX B

United States Patent Office

2,800,631
Patented July 23, 1957

2,800,631

METHOD OF CARRYING OUT MELTING PROCESSES

Theodor Eduard Suess, Luxembourg, and Herbert Trenkler, Hubert Hertzmann, and Rudolf Rinesch, Linz (Danube), Austria; said Suess assignor to Vereinigte Österreichische Eisen- und Stahlwerke Aktiengesellschaft, Linz (Danube), Austria, a corporation of Austria

Application Nov. 16, 1955, Serial No. 547,233

2 Claims. (Cl. 75—60)

This invention relates to a process for the treatment of metallic or metal-containing materials with oxygen-containing gases, preferably high purity oxygen, and has particular relation to a process of this type in which fusible materials are treated at high temperatures with said gases. Still more particularly, the invention relates to a process for the refining of molten metal with high purity oxygen blown downwardly onto the surface of a bath of the molten metal.

The invention is particularly adapted to the refining of primarily hot metal charges, for example, molten pig iron, but it is also applicable to the production of refined metals from solid charges, such as solid pig iron for the production of steel, as hereinafter set forth. The invention is also characterized by the fact that the heat required for the refining of the molten impure metal is autogeneous, being produced primarily by reaction of the oxygen gas with the impurities in the molten metal, although when utilizing solid charges of impure metal, the heat required for melting of the charge prior to refining is provided by combustion of a suitable fuel with the oxygen gas.

Processes for the utilization of high purity oxygen in the refining of molten metal charges, such as pig iron, have been suggested ever since the development of the original pneumatic process by Bessemer. Attempts to blow with high purity oxygen in a conventional Bessemer or Thomas converter through bottom tuyeres has resulted in the destruction of the refractory bottom within the short time of one heat. On the other hand, high purity oxygen refining processes have been previously proposed in which the oxygen is directed onto the molten metal bath surface in the form of a jet or jets issuing from tuyeres positioned in the wall of the refining vessel above the melt line. In such processes, the horizontal velocity component of the oxygen jet at the melt surface causes the development of excessively high temperatures above and at the melt-slag interface on the side of the vessel opposite the tuyeres or oxygen jet inlet so that a rapid deterioration of refractory occurs. In addition, with such an inclined oxygen jet, a loss of oxygen efficiency results due to deflection of the gas from the melt surface and burning of a large proportion (40–50%) of the evolved carbon monoxide to carbon dioxide above the melt, which is further undesirable in contributing to the short refractory life. In addition, the heat produced by high purity oxygen-molten metal reactions is more than sufficient to provide the heat necessary for completion of the refining reactions to the desired steel analysis, and this large amount of additional heat developed within the refining vessel due to carbon monoxide combustion is undesirable. Further, in the utilization of high purity oxygen as the refining medium, the reduction in oxygen efficiency resulting from this combustion of the carbon monoxide with a portion of the oxygen fed cannot be tolerated.

Accordingly, it is recognized that the application of such processes, in which the molten materials, for example pig iron, are treated in refining devices provided

with refractory linings are severely limited due to the extremely high temperatures developed by reaction of the high purity oxygen gas with the molten metal and the short life of the refractory linings when exposed to such temperatures. This is particularly true in those processes, such as production of steel, in which chemical reactions capable of causing corrosion of the refractory lining take place. Thus, in a device provided with refractory lining, such as a converter in the previously proposed processes when high purity oxygen is blown to the surface of a bath of molten pig iron, with or without a slag cover, combustion of the impurities in the metal, and also iron itself result in such extremely high temperatures that the refractory lining is attacked and damaged to such extent that it must be renewed after a short period of use. The refractory materials known at present are unable to resist attacks and stresses of this kind unless the lining is protected by the application of particular conditions from direct exposure to the strong heat developed by the high purity oxygen-molten metal reactions. Accordingly, although the advantages of molten metal refining with high purity oxygen have been recognized, particularly with respect to the reduced nitrogen ballast compared to the air blown pneumatic refining processes, there remains no economical, commercially feasible process for refining of molten metal with high purity oxygen capable of providing long refractory life and high oxygen efficiency. In particular, the deficiencies of the proposed processes, emphasize the lack of a high purity oxygen refining process for molten pig iron having the aforementioned advantages to provide an economical, commercially feasible process for production of refined steel at least equal in quality to that produced by the well known basic open-hearth process from pig iron of widely varying chemical compositions.

It is accordingly one of the main objects of the present invention to provide a process for refining molten metals by surface blowing with high purity oxygen, in which, owing to the particular conditions employed, the refractory walls of the apparatus utilized in carrying out the process are protected from undue corrosion by the excessively high temperatures developed and the chemical reactions taking place at such temperatures.

Another object of the present invention is to carry out the treatment of molten metals, and other molten materials by surface blowing with high purity oxygen in such a manner that the reactions of the oxygen gas with the constituents of the molten bath and the resulting high temperatures, to the extent possible, are limited to an oxygen jet impingement area removed from the refractory lining of the reaction vessel.

It is also a primary purpose and object of this invention to provide a process for the refining of primarily hot metal charges, that is, predominantly molten pig iron, with high purity oxygen gas in which controlled refining at substantially theoretical oxygen efficiency is accomplished.

A further object is to provide a process for refining of molten pig iron with a surface blown high purity oxygen jet in which an exceptionally high refractory life is obtained.

The invention also has as its object to provide a process of surface blowing molten pig iron with high purity oxygen in which the refining reactions and oxygen impingement on the melt surface are controlled in a manner such that over-oxidation of the molten pig iron bath is essentially avoided.

It is still another object of the invention to provide a high purity oxygen refining process which is applicable to pig iron of widely varying chemical compositions, including in particular pig iron of analyses used in or-

dinary basic open-hearth practice, as well as those of higher silicon and phosphorus content required for blowing in the acid Bessemer and basic Thomas converter processes to produce steels having analyses and qualities at least comparable to that of basic open-hearth steels. Another object of the invention is to provide a high purity oxygen refining process for production of steel of excellent quality at a high rate of production, substantially comparable to Bessemer or Thomas converter practice, for example, a blowing time of from 15 to 30 minutes for charges of from 30 to 40 tons to carbon end points of 0.05% or below.

Further objects and advantages of the invention will be apparent from the following detailed description of the process and the appended drawing.

The process of the invention generally comprises refining the molten metal in a converter type or other suitable vessel with a high purity oxygen jet impinging vertically or approximately vertically on the melt surface substantially at the central portion thereof by means of a blast nozzle or other suitable jet producing means under controlled conditions, hereinafter defined, to supply to the molten metal the required amount of oxygen for completion of refining within a predetermined time, and to produce autogenous heat sufficient to insure completion of the refining and adequate temperature in the refined charge for subsequent handling.

It has been found that by suitable arrangement of the nozzle or jet producing device, and operation thereof for the supply and introduction to the molten metal of the high purity oxygen gas, suitable design of the refractory lined refining device in which the process is conducted, and proper use of amounts of materials charged, the foregoing advantages are obtained, including a very efficient protection of the refractory lining.

According to the process of the invention, the high purity oxygen jet is blown vertically, or approximately vertically upon the central portion of the surface of a bath of the molten metal, the jet having a diameter and static pressure at the point of origin, that is, at the blast nozzle or other jet producing means, and the point of origin (blast nozzle) being spaced from the bath surface, such that direct contact of the oxygen jet and the molten metal is established and maintained throughout the refining period without deep penetration of the molten metal bath by the jet. In so operating, the area of jet impingement is controlled to produce a relatively confined zone of direct oxygen to molten metal contact with respect to the total surface area of the bath. It has been determined in application of the present invention to the refining of predominantly molten pig iron charges by means of high purity oxygen, that the jet blown onto the surface of the molten iron, as above described, under a relatively low static pressure at the point of origin, for example, at the overhung blast nozzle, of from 5 to 25 atmospheres (about 75 to 375 pounds per square inch), preferably at about 8 to 12 atmospheres (about 115–175 pounds per square inch), with the jet diameter at the point of origin or blast nozzle being about 1 millimeter (1/25 inch) per ton of charge, and with the point of origin or blast nozzle spaced from the bath surface from at least 150 millimeters (about 6 inches) up to about 2000 millimeters (about 80 inches), produces a sufficiently high reaction velocity of the oxygen with the bath constituents to insure the development of autogeneous heat at a rate sufficient to provide the heat required for completion of the refining in a minimum of time, consistent with controlled temperature and control and development of other necessary and required process conditions, such as fluid slag, avoidance of overoxidation (undue loss of iron to the slag), and avoidance of slopping. The process conducted under these conditions avoids a deep penetration of the oxygen gas into the molten bath which seriously impairs refractory life at the bottom of the refining vessel. In addition, the impingement area of the high purity oxygen on the central portion of the bath isolates the refractory walls of the refining vessel from the extremely high temperatures which are developed by the direct reaction of the oxygen and the molten metal.

It has also been found, according to the invention, that the utilization of suitable design of reaction vessel and the use of the proper amount of material charged results in a ratio of the depth of the bath to the surface area of the bath which augments the protection afforded to the refractory lining of the refining vessel and is also beneficial to the progress of the refining reactions to produce finished steels of low impurity content comparable to those produced by the basic open-hearth process. In carrying out the process of high purity oxygen refining of a molten bath of pig iron, the refining vessel is of such design and the charge is of such amount that the ratio of the depth of the molten bath in meters to the surface area of the molten bath in square meters should be from about 1 to 5 to about 1 to 28 in refining vessels of various design or in terms of the ratio of depth to diameter of a circular bath between 1:2.5 and 1:19. In other metallurgical processes to which the present invention is adapted substantially similar ratios may be used.

Although it is not intended to limit the present invention to any specific theory of action or mechanism, it is believed that application of the oxygen jet substantially vertically or approximately vertically upon the central portion of the bath surface brings about a flow in the molten metal from the center of the surface of the bath downwardly and then along the bottom of the refining vessel, and upwardly at the sides of the vessel to the surface of the bath, so that portions of the unrefined metal are continuously presented to a localized center of direct oxygen reaction with the bath metal, while reacted or oxidized portions of the bath move away from this reaction center. This apparent circulation of the molten material is facilitated by shaping of the bottom of the device in its refractory lining in a uniformly curved design, preferably hemispherical or similar shape, so as to offer the minimum of resistance to the circulation.

Due to the very high affinity of oxygen for iron, initial contact of the high purity oxygen jet with the molten metal bath causes a rapid combination of oxygen and iron to form FeO in the confined central reaction zone. This is demonstrated by ignition of the oxygen and the propagation of a visible flame within the first minute of blowing. This reaction, together with oxidation of impurity elements, such as silicon and manganese, develops extremely high temperatures in the zone of direct oxygen contact with the molten metal which approach the boiling point of iron, as demonstrated by the evolution of a fume containing iron oxide and manganese oxide. A portion of the iron oxide goes to the slag with the other oxidized elements and a portion diffuses into the bath under the influence of the bath circulation, so that within the first three minutes of the blowing vigorous carbon combustion is initiated due to the high temperatures developed by these reactions. The ensuing reaction of carbon with the FeO and directly with the oxygen gas in the confined direct oxidation zone causes rapid formation of carbon monoxide and the formation of this CO causes a strong boil or agitation of the bath, which augments the bath circulation to continuously present unrefined metal to the oxygen gas reaction zone and to create a slag-metal emulsion. The oxygen jet thus contacts the emulsion of bath and slag components which presents a larger reaction surface and causes the refining reactions to progress rapidly although the oxygen jet does not penetrate deeply into the molten metal bath and is confined to an impingement area at the central portion of the bath surface. This vigorous boiling action is opposed by the pressure of the oxygen jet only in the area of impingement, and outside of this area it represents primarily endothermic

Suess et al. Patent 2,800,631.

reduction of FeO by carbon to form the evolved carbon monoxide, which reaction thus effectively encompasses the zone of direct oxygen reaction at which the highest temperatures prevail affording a maximum measure of protection to the refractory lining of the refining vessel.

In conducting the process in the manner set forth above, the advantage of exceptionally high refractory life is obtained. For example, in refining of pig iron having the following chemical composition: carbon 3.8–4.2, silicon 0.6–1.3, manganese 1.4–2.2, phosphorus 0.120–0.250, and sulfur 0.045 max., and a slag having the following composition SiO_2 12–17%, CaO 38–44%, MgO 3–10%, MnO 9–13%, P_2O_5 1.2–1.8%, and Fe 12–17%, in a 30 ton converter, the average durability of the refractory is over 200 heats (foregoing in percentages by weight). By comparison, in basic Bessemer practice utilizing air rather than high purity oxygen, the removable converter bottom must be relined after only 35 to 60 heats. In addition, the refractory life obtainable by the process of the invention surpasses that obtained in normally operated open-hearth practice in that in refining of a normal charge by basic open-hearth about 36 lbs. of refractory brick is consumed per ton of steel produced to which must be added some 40 pounds of sintered dolomite for fettling operations, whereas total refractory consumption in the instant process is only about 24 lbs. per ton of steel produced. This advantage is even greater when compared to oxygen lancing in an open-hearth which accelerates refractory consumption.

The further advantage of high oxygen efficiency is obtainable according to the process of the invention when the oxygen jet impinges on the central portion of the molten bath surface from directly above, that is, approximately vertically. Oxygen efficiencies calculated on the basis of total oxygen input compared to oxygen consumed in the bath reactions is approximately 95%. This is demonstrated by an average oxygen consumption of only 57 normal cubic meters (measured at standard conditions of temperature and pressure) per ton of steel including oxygen consumption for heating the converters after relining. This compared with calculated or theoretical oxygen requirements for the refining of the various pig irons blown to steel analyses set forth below represents about a 95% efficient utilization of oxygen. In addition, analyses of waste gases effluent from the converter indicate that the carbon in the instant process burns almost 100% to carbon monoxide, the analyses showing on the average over 90% CO and less than 10% CO_2, indicating that the oxygen input is not lost by burning with the carbon monoxide above the melt within the refining vessel, as in the case of low angle impingement from tuyeres positioned in the side walls of the refining vessel. Moreover, this is a distinct advantage in the instant process, since the reaction of the oxygen with the melt provides more than sufficient heat for the refining, and additional heat by burning of the carbon monoxide to carbon dioxide above the melt is to be avoided. The potential heat units in the effluent carbon monoxide may be utilized in various ways by subsequent burning.

As above mentioned, it is a characteristic of the process of the invention that in the confined zone of direct oxygen reaction at the surface of the molten metal bath, the oxidation products of the impurities in the pig iron, such as silicon and manganese, as well as the oxidized iron form an early fluid slag which is always very rich in oxides, that is, highly oxidizing. With the formation of the slag-metal emulsion, the iron oxide reacts with the carbon present in the bath, primarily outside of the direct oxygen-metal reaction zone, and since such slag-metal reactions are endothermic, the molten bath is maintained cooler in the vicinity of the walls of the refining vessel or converter. For example in the formation of one kg. of FeO, by direct oxidation with the oxygen jet and absorbed as iron silicate into the slag, 80 kg. calories of heat are developed. An equal amount of heat is absorbed outside

of the confined central zone of direct oxidation as the FeO (as silicate) is reduced by the carbon in the bath, as one example of slag metal reactions occurring during the blowing.

This formation of an early highly oxidizing fluid slag is of particular value in basic refining when the process is applied to pig iron of analyses used in ordinary open-hearth practice, which would not be amenable to refining by either the acid Bessemer process due to the phosphorus content, or the basic Thomas process due to the lack of sufficient phosphorus. With the rapid heating of the slag cover and metal bath, the proper amounts of lime or lime supplying substance, such as limestone, may be added at the beginning of the blow and during the blow to insure formation and maintenance of a slag of sufficient basicity. Thus, the early fluid, basic and highly oxidizing slag formed provides an accelerated rate of phosphorus and sulfur removal from the bath, leaving the finished steel very low in both elements. With normal open-hearth pig irons having phosphorus contents ranging from about 0.1–0.35%, and even higher, e. g., 0.85% P, and with correct lime additions, final phosphorus contents not higher than about 0.025% and as low as 0.010% are obtained by the time the carbon end point is reached with only a single slagging operation. With sulfur contents in the pig iron of from 0.045 to 0.08%, the sulfur is decreased to 0.02–0.025%, and on the lower range of sulfur in the pig iron to values as low as 0.012%. In usual operations, from 1 to about 4.5% lime is charged to obtain the foregoing result, depending upon the phosphorus content in the pig iron. In addition, all of the lime requirement may be added during initial charging before blowing is started, particularly where the silicon content of the pig iron, which is one of the first oxidized elements, is sufficiently high. On the other hand, the lime may be charged in increments during the blow, but with a sufficient amount initially charged to provide a basicity adequate to absorb the phosphorus.

In the normal range of phosphorus in pig iron of basic open-hearth quality from about 0.1 to 0.35%, the required slag volume including the lime charge is advantageously much lower than the slag volume in the bottom blown basic Thomas process. The iron content of the slag varies from about 9 to 18%, with generally higher FeO content in the slag at higher phosphorus contents in the pig iron, and also at lower manganese contents. Accordingly, the lower percentage of slag, for example, 11 to 12% compared to about 22% in the Thomas process results in comparable or lower total iron content lost to the slag, even though the FeO content of the slag may be higher than the usual 10% in the basic Thomas process.

The process in its preferred embodiment utilizes high purity oxygen, by which the term is meant oxygen gas analyzing at least 97% O_2. For minimum nitrogen content in the finished steel of at least 98% oxygen and preferably 99% or higher should be utilized. The frequency curves based on produced steel analyses indicate that oxygen of at least 98% purity provides a peak or maximum at a nitrogen content of from 0.002 to 0.003%, with 95% of all heats blown showing a nitrogen content of 0.004% or less.

The vigorous boil, above mentioned, continues up to the carbon end point, and together with the induced circulation of the bath metal toward and away from the central zone of direct oxygen reaction, effectively counteracts any tendency to overoxidation of the bath. When the flame dies and carbon combustion is completed, the bath becomes relatively quiet and intimate contact between slag and metal bath ceases. The turbulence of the bath and slag due to the oxygen stream impinging from directly above is insufficient to cause continuance of oxygen-metal reactions. As a result, steels blown by the process of the invention do not suffer from the deteriorating effects of high oxygen (FeO) contents. Direct oxygen determination by the hot extraction method yielded oxygen con-

tents of 0.04% maximum for heats that were blown to a carbon end point of from 0.03 to 0.10% C. Thus, the oxygen content of steels produced by the high purity oxygen blowing process compare very favorably with oxygen contents of basic open-hearth steel in the same carbon range, and are definitely lower in oxygen content than bottom blown Bessemer steels using air, oxygen enriched air, oxygen and steam, or other gas mixture.

As in the basic Bessemer process, the silicon is rapidly eliminated. However, in contrast to the basic Bessemer process, the use of high silicon charges presents no problem due to the fact that slopping is not encountered in the process of the invention to any degree similar to that in the bottom blown Bessemer practice. In fact, higher silicon pig irons actually are advantageous in the high purity oxygen blowing due to the heat producing effect of this element in the early stages of the blow with the result that higher scrap charges can be made in the process.

Regarding scrap additions, the process advantageously may utilize scrap charges of up to about 30%, depending primarily upon the silicon content of the pig iron, and also on the temperature of the hot metal charge. For lower ranges of silicon, such as 0.3 to 0.7% scrap charges of from 10 to 15% are permissible. With silicon in amounts from 1 to 1.2%, scrap charges of 20 to 25% may be utilized.

In general, the manganese content of the fully blown metal and of the slag increases with the total manganese content (pig iron and scrap). However, it is a characteristic of the oxygen steel making process that the high temperatures developed in the reaction zone between the bath metal and the slag cause a rereduction of manganese from the slag into the bath during the latter portion of the refining period. In the last minutes of the blow, the manganese content in the bath again decreases as the carbon drops to its final value, that is, at a normal end point of 0.04–0.06. Accordingly, the manganese content in the finished steel and in the slag is subject to some control, and is governed by slag composition and volume, temperature and final carbon content. With the use of a minimum amount of slag rich in iron oxide, for example only 70 kg. per ton of steel, the amount of loss of manganese to the slag by burning may be considerably reduced. As above mentioned, extensive tests have shown that the amount of slag can be kept considerably lower than the conventional pneumatic process, such as the Bessemer and Thomas processes. Under these conditions of high developed temperature in the refining process and low slag volume with high iron oxide content, a finished steel containing manganese in quantities at least 10 times the amount of carbon, for example, 0.6 to 0.8 Mn at carbon end points of 0.03% are obtainable. Accordingly, it is possible to pour rimming steels down to relatively very low carbon contents without any addition of manganese and deoxidizing agents. Under actual operating conditions the best practice for production of standard grades is to refine down to 0.06–0.08% C and to recarburize in the ladle. This practice results in a manganese content of from 0.6 to 0.8 and eliminates the necessity for manganese additions to conform with the usual analysis specifications. The above manganese content easily compares with the conventional composition of rimming low-carbon open-hearth steels, in fact such analyses are near the upper limit of the range. It is also possible to catch the heat at higher carbon contents, so that the resulting content in manganese will be of a higher order than is normally encountered in rimming open-hearth steels of identical carbon content. Thus, it is possible to produce rimming low carbon high purity oxygen blown steels of a predetermined strength which is based on an inherently higher manganese content of the heat.

It has also been found that a steel containing 0.1% carbon and as high as 1.5% manganese may be obtained, for example by the addition of ordinary blast furnace

ferromanganese, e. g., 15 kg. of 48% blast furnace ferromanganese per ton suffices, and results in an increase of about 0.05% in the carbon content. In normal steel making operations it was not previously possible to obtain such steels without the use of expensive refined ferromanganese products. Steels of such analyses, not only exhibit increased toughness and yield strength but other properties, such as pressure weldability, are improved.

To exemplify the high manganese recovery in the steel without ferromanganese additions after the blow, the results of the following heats are provided. As indicated above, since the manganese content, under otherwise equal conditions, increases in the finished steel with increase in pig iron, it is to be noted that particularly high manganese content pig irons were employed. Nevertheless, it is evident that due to the extremely high temperatures developed in this high purity oxygen process, a manganese recovery is possible which cannot be reproduced in known processes.

Heat No. 1.—Pig iron analysis: 4.16% C, 3.02% Mn, 0.14% Si, 0.074% P, 0.040% S. Last converter control test (without ferromanganese or deoxidizers): 0.09% C, 0.96% Mn, 0.005% Si, 0.039% P, 0.013% S, 0.007% Na.

Heat No. 2.—Composition of pig iron: 4.30% C, 3.24% Mn, 0.33% Si, 0.072% P, 0.034% S. Last converter control test (without ferromanganese or deoxidizer): 0.08% C, 1.02% Mn, 0.005% Si, 0.037% P, 0.010% S, 0.004% Na.

Heat No. 3.—Composition of pig iron: 4.21% C, 2.88% Mn, 0.27% Si, 0.076% P, 0.044% S. Last converter control test (without ferromanganese or deoxidizer): 0.07% C, 0.93% Mn, 0.005% Si, 0.037% P, 0.012% S, 0.004% Na.

From the foregoing test, it may be seen that manganese recovery at least 10 times as high as the final carbon content in the finished steel is obtainable by the process of the invention utilizing pig iron having manganese on the order of 3%.

In regard to output, the combustion of the impurities of the pig iron and the iron content of the slag total a loss of about 8.0% with an additional 0.8% of iron lost in the dust fume from the process. With mechanical losses averaging about 0.8%, the percentage recovery of the refining process is approximately 90%, comparable to the yield obtainable by the basic open-hearth process. In the progress of the high purity oxygen blowing, up to about the eighth minute, oxidation of the iron progresses under formation of comparatively large amounts of FeO, which, as above stated, promotes a desirable quick liquefaction of the basic lime slag. At this stage in the blow, the slag shows maximum values of from 25–30% FeO. In the further course of the process reduction of Fe from the slag occurs which continues until the carbon content of the bath of about 0.07% is reached. The FeO in the slag decreases to about 10–12%. On further removal of carbon, the FeO in the slag again increases so that in the final slag generally an iron content averaging 14% is obtained, and only at very low carbon heats does the iron content exceed this value.

Under these known metallurgical conditions above set forth, the total oxygen requirement is calculated on the basis of oxygen pick-up of the heat during the refining period. Summation of these oxygen gas volumes required for the oxidation to complete refining indicates substantially a straight line function on oxygen input, and corresponding to this relative constancy of oxygen input, the oxygen pick-up proceeds uniformly during the blow. The oxygen input is maintained at a rate such that the speed of the refining process insures satisfactory rereduction of FeO from the slag, in the manner set forth above. In actual practice, based on experience in operation of 30 ton converters, oxygen feed rates may be maintained such that depending upon pig iron analysis, amount of scrap addition and desired finished steel analysis, the

refining to usual carbon end points on the order of 0.05% C is completed in from about 15 to about 30 minutes, preferably 18 to 22 minutes. Flow rates of from about 4000 to 8000 cubic meters of oxygen per hour are representative of the oxygen input under these conditions.

In such exemplary commercial practice with 30 ton converters charged to 35 to 36 tons, oxygen pressures at the blast nozzle of about 8 to 10 atmospheres and oxygen jet or blast nozzle diameters of from about 27.5 to 35 millimeters (1.1 to 1.4 inches) with nozzle spacings varying from 25 to 50 inches (about 650 to 1250 millimeters have been used, the preferred spacing being from 30 to 40 inches (about 750 to 1000 millimeters). In general, it may be stated that as the oxygen pressure and nozzle diameter are increased, the nozzle spacing is also increased, for example, as the capacity of the refining vessel and total charge is increased. Under these conditions, deep penetration of the molten metal bath is avoided, while the necessary displacement of the slag cover to maintain direct oxygen to molten metal contact is insured. However, in the unusual circumstances of an abnormally stiff slag cover, the blow may be initiated using mechanical means for penetrating the slag cover to establish oxygen to metal contact.

It is to be noted, that in certain instances particularly where the rate of oxygen input is relatively high, that is, the total blowing time is in the lower portion of the range above stated, the pressure of the oxygen jet at the blast nozzle may be reduced in the last few minutes of the blow to reduce the rate of oxygen input, which is beneficial in supporting the inherent characteristic of the process in regard to avoidance of over-oxidation of the heat. Due to this characteristic of the process, it is generally unnecessary to utilize any deoxidizing agents such as ferromanganese and ferrosilicon in the production of semi-killed steels, and only in the production of killed steels are the conventional deoxidizers employed.

The process has as one of its major advantages the applicability to pig iron of analyses used in ordinary open-hearth practice, which would not be amenable to refining by either the acid Bessemer process or the basic Thomas process. In addition, the process is fully applicable to pig irons having analyses of the type which are normally utilized in either the acid Bessemer or basic Thomas processes. Typical illustrations of the following pig irons and the finished steels produced therefrom indicate that the process produces steels comparable to open-hearth quality from pig irons of widely varying phosphorus and silicon contents.

(1) 4.0% C, 1.5–2.0% Mn, 0.7–1.2% Si, 0.1–0.24% P, 0.05% S, and 0.01% N blown to a finished steel of the following analysis: 0.06% C, 0.35% Mn, 0.00% Si, 0.026% P, 0.025% S, and 0.0025–0.0035% N (oxygen about 98%).

(2) Pig iron analyzing 3.6–4.25% C, 1.4–3.2% Mn, up to 0.3% Si, 0.06–0.1% P, 0.04–0.07% S, and 0.01% N from which steel of the following analysis is obtained: 0.06% C, 0.35% Mn, 0.00% Si, 0.01–0.02% P, 0.022% S, and 0.001–0.002% N.

(3) Illustrative of a grade of pig iron falling between that of normal open-hearth analysis and basic Bessemer pig iron is the following: 3.61% C, 2.16% Mn, 0.46% Si, 0.856% P, 0.062% S. Blowing of such a charge of rather unfavorable chemistry by the process of the invention yielded a steel of the following composition: 0.04% C, 0.15% Mn, 0.0% Si, 0.014% P, 0.045% S Clearly, such a pig iron would be definitely unsuitable for basic Bessemer (Thomas) process refining, and would also present considerable difficulty if used for open-hearth refining.

The accompanying drawing diagrammatically illustrates a device for carrying out the present invention. In this drawing, reference numeral 1 denotes a metallic wall and 2 the refractory lining of the refining vessel. An oxygen supply lance 3 is centrally positioned and overhung above the charge and is provided with a nozzle

3' for the introduction of the oxygen gas, inserted in an opening of the cover 4. The material charge, including molten pig iron, molten scrap, and slag forming additions, such as limestone, is indicated at S and the depth and diameter of the upper surface of the molten mass in the quiescent state are denoted by H and D, respectively. The lance 3 is retractable, and is provided with water cooling ducts and connections (not shown). The cooling water in actual practice is supplied to the lance at a pressure of from 4 to 6 atmospheres and the normal flow rate is about 36 to 40 cubic meters per hour. Under such conditions the temperature of the cooling water increases from approximately 14° centigrade input to a maximum of about 50° centigrade in the effluent from the lance.

In the preferred commercial practice of the invention, a converter shaped vessel with an open mouth is usually provided, through which the lance is inserted into and retracted from operating position, as indicated in the example set forth below. In this manner, suitable gas take off devices may be positioned at the throat of the converter type vessel to collect the off gases and separate the particulate fume therefrom.

The following is a detailed description of a typical operation of the process, which is not to be regarded as a limitation on the invention, but rather as a complete specific embodiment thereof.

Example I

A closed bottom converter of normally 30 tons (metric) capacity is charged with a total of about 36 tons of metal through an open mouth. The oxygen lance is inserted through the mouth of the converter to the adjusted distance above the melt surface. The diameter of the surface of the bath with such a charge is about 3 meters and the depth of the bath about 1 meter. A typical cycle of operations is given below on a time table basis.

	Hours
7100 kg. plant return scrap charged to converter	0
29,600 kg. pig iron poured from mixer into converter having an analysis as follows: 4.04% C, 0.99% Si, 1.73% Mn, 0.153% P, and 0.043% S	0.08
Addition of 850 kg. limestone and 60 kg. bauxite	0.10–0.13
Introduction of nozzle, oxygen jet initiated at a nozzle pressure of 10 atmospheres (147 P. s. i.) with a nozzle spacing above the bath of 1000 millimeters	0.15
850 kg. limestone and 200 kg. rolling mill iron slag added	0.16
750 kg. limestone chips added in five parts of 150 kg. each	0.22–0.28
Oxygen pressure reduced to 8 atmospheres	0.30
Mouth flame transparent, nozzle withdrawn, oxygen supply turned off—end of blowing time at 19 minutes	0.34
Converter contents sampled and analyzed as follows: 0.05% C, 0.00% Si, 0.31% Mn, 0.024% P, 0.02% S	0.35
Slag drawn off	0.35–0.39
150 kg. Spiegel iron added to contents of converter	0.39
Slag remaining in converter stiffened with 30 shovelfuls of limestone	0.39–0.42
Steel poured into pan, temperature measured at 1575° C., 6 kg. electrofluor added to pan	0.42–0.45

Final test analysis on pouring into ingot mold was: 0.07% C, 0.32% Mn, 0.022% P, 0.020% S, 0.0035% N. Oxygen consumption 1950 cubic meters. This oxygen consumption is about 54 cubic meters (measured at standard conditions) per ton and compares with a theoretical oxygen requirement of 51 cubic meters (measured at standard conditions), and therefore indicates an oxygen efficiency of 95%.

11

The process of the present invention may be also applied to the production of metals, for example, production of steel, from solid starting materials. In the production of steel, pig iron and scrap iron, and if desired certain alloys and fuels, such as coal or wood, are introduced into the refining vessel. As materials for producing heat for melting, coke, ferrosilicon, calcium carbide, aluminum alloys and the like, which are converted into slag or gaseous products at the prevailing refining temperatures can be added. The total amount of the starting material mixture may be introduced as a single charge prior to initiation of the melting, or may be gradually fed in small incremental amounts. Sufficient fuel should be present for producing the combustion necessary to provide the heat of fusion of the solid charge. After ignition of the fuel, melting of the initial mixture is brought about by the action of the oxygen jet.

The melting procedure is started by means of an ignited body which is introduced immediately prior to the initiation of blowing of the oxygen jet, and is preferably positioned at that portion of the solid charge where the oxygen jet comes in direct contact therewith.

Thus, according to the present invention, a steel may be produced with a minimum consumption of fuel, for foundries or rolling mills, by melting the iron to be converted into steel with low grade fuel and a high purity oxygen jet blast, for example, in cupola furnace, or in a converter type vessel itself, and subjecting the thus melted solid charge to high purity oxygen refining in the above described manner in a suitable refining vessel, such as a converter. In carrying out such a melting and refining treatment with high purity oxygen, the energy consumption is extremely low, amounting to only 100 cubic meters of oxygen (measured at standard conditions) per ton of steel produced. Of course, as indicated above in the refining of primarily hot metal charges constituting pig iron with analyses as set forth above to refine steels of 0.05% carbon content and analyzing as above indicated, the average oxygen consumption is only about 57 cubic meters per ton (measured at standard conditions).

The present process of surface blowing with high purity oxygen is also applicable to the desulfurization of copreous materials and to the production of glass in the converter with the use of sodium chloride. Furthermore, the process is applicable to the treatment of blast furnace slag to the elimination of sulfur and conversion of slags into melted cement or glass-like materials of the type used for the manufacture of slag wool.

12

This application is a continuation-in-part of my copending application Serial No. 206,147, filed January 16, 1951, now abandoned. It will be understood that the present invention is not limited to the specific materials, steps and other specific details described above and may be carried out with various modifications without departing from the scope of the invention as defined in the appended claims.

We claim:

1. Method of refining molten impure iron in the presence of a slag in a vessel having a refractory lining by blowing with oxygen, which comprises discharging a stream of oxygen vertically downwardly through the slag layer onto and below the surface of the bath at the central portion thereof, to an extent to avoid material agitation of the bath by the oxygen stream, the contact of the oxygen with the bath resulting in reaction of the oxygen with a portion of the iron and with the oxidizable impurities of the bath in a localized reaction zone spaced a substantial distance from the refractory lining, the reactions in said zone resulting in refining of the iron and gas evolution and in the production of high temperature in the reaction zone away from the refractory lining, said reaction producing a circulatory movement in the molten metal, which circulatory movement brings those portions of the molten metal bath which are remote from the reaction zone into the reaction zone whereby those portions are subjected to said reaction with minimum injury to the refractory lining.

2. The gaseous oxygen process set forth in claim 1 in which the oxygen is blown into said vessel under pressure in a range between about five and about twenty-five atmospheres above normal atmospheric pressure.

References Cited in the file of this patent

UNITED STATES PATENTS

1,032,653	Brassert	July 16, 1912
2,515,631	Cheswik	July 18, 1950
2,598,393	Kalling et al.	May 27, 1952
2,741,555	Cuscoleca et al.	Apr. 10, 1956

FOREIGN PATENTS

623,881	Great Britain	May 24, 1949
642,084	Great Britain	Aug. 30, 1950
983,098	France	Apr. 5, 1948

Claim 1 of Suess et al. Patent No. 2,800,631

Method of refining molten impure iron in the presence of a slag in a vessel having a refractory lining by blowing with oxygen, which comprises discharging a stream of oxygen vertically downwardly through the slag layer onto and below the surface of the bath at the central portion thereof, to an extent to avoid material agitation of the bath by the oxygen stream, the contact of the oxygen with the bath resulting in reaction of the oxygen with a portion of the iron and with the oxidizable impurities of the bath in a localized reaction zone spaced a substantial distance from the refractory lining, the reactions in said zone resulting in refining of the iron and gas evolution and in the production of high temperature in the reaction zone away from the refractory lining, said reaction producing a circulatory movement in the molten metal, which circulatory movement brings those portions of the molten metal bath which are remote from the reaction zone into the reaction zone whereby those portions are subjected to said reaction with minimum injury to the refractory lining.

PX-2A, pp. 72-77.

Remarks in Amendment of June 11, 1957 in Suess et al. Application Serial No. 547,233

[PX-2A, pp. 72-77]

IN THE UNITED STATES PATENT OFFICE

Applicant : Theodore E. Suess
Serial No. : 547,233
Filed : November 16, 1955 Div. 3
For : METHOD OF CARRYING OUT MELTING PROCESSES

Hon. Commissioner of Patents
Washington , D. C.

* * * * * * *

REMARKS

A letter is directed to the Chief Draftsman requesting the addition of the names of Messrs. Trenkler, Hauttmann and Rinesch to the drawing.

The applicants make claim to the right of priority under the provisions of 35 USC Section 119 to the filing dates of the following Austrian applications:

Application No. A 480/50, filed January 31, 1950
Application No. A 588/50, filed February 6, 1950
Application No. A 1051/50, filed March 1, 1950
Application No. A 1318/50, filed March 13, 1950

Certified copies of the Austrian applications were furnished during the prosecution of the Suess application Serial No. 206,147 in support of a claim of priority therein.

PX-2A, pp. 72-77.

The claims of the application are cancelled and new claims 17 and 18 are substituted therefor in view of the discussion with the Examiner on May 1, 1957.

The new claims are presented in view of information recently made available and which indicates that the instant application discloses a fundamentally different approach to the refining of pig iron or crude iron by means of substantially pure oxygen than was suggested heretofore. The new claims are believed to be properly definitive of the invention.

The applicants, as early as June, 1949, were familiar with methods of refining crude iron or pig iron proposed by the patentees of the Miles et al. French patent No. 933,098 and the Schwartz German Patent No. 735,196. The applicants assumed that the Schwartz and Miles et al. methods were suitable for the production of steel of commercial quality and the applicants attempted to use these methods in their early work. They injected substantially pure oxygen into the molten metal at supersonic velocity from a nozzle closely spaced with respect to the surface of the molten metal so that the jet of oxygen penetrated deeply into the bath of molten metal and agitated the bath violently. The early work with these operating conditions was a complete failure because the quality of the steel (if it could be called steel), was very poor and the reaction resulted in rapid destruction of the refractory lining of the converter in which the blowing operations were conducted. The reaction of the gaseous oxygen with constituents of the bath produces intense heat and the impingement of the intensely heated components or products of that reaction upon the refractory surfaces confining the bath

tends to produce rapid deterioration of the refractory surfaces.

The applicants determined that it was possible to convert the bath of pig iron into steel of commercial quality by blowing the bath with high purity oxygen if the reaction is limited to a part of the bath which is remote from the refractory walls. When the reaction is carried out only in the central part of the upper surface of the molten metal and the central part of the body of the bath of molten metal, out of contact with the refractory surfaces, the circulation induced by the centrally disposed reaction zone subjects the entire contents of the bath to the oxidizing reaction resulting in a uniformly treated product without impinging the high temperature reaction products upon the refractory walls. In other words, by carrying out the reaction in the cental region of the bath remote from the side and bottom surfaces of the refractory lining or walls, the reaction occurring in said central region brings the entire contents of the bath progressively into the reaction zone for reaction with oxygen without producing the destructive effect upon the walls of the container and without the production of an excessively high oxide content in the refined metal. In this way, the applicants were able to turn failure into success by a change in operating conditions which was relatively simple, when once recognized.

An affidavit by Rudolph Rinesch is submitted herewith, the affidavit being supported by an exhibit which shows the early work done by the applicants with the processes taught by Schwartz and Miles et al. and with the new process developed by the applicants. To facilitate the Examiner's understanding of the exhibit an-

PX-2A, pp. 72-77.

nexed to the affidavit, we are enclosing English translations of the terms appearing on the exhibit and the marginal notes at the right-hand end of the exhibit.

It should be noted that test No. Br13 is obviously erroneous in specifying a phosphorous content of 0.96% and was not relied on in the affidavit. Explanation of the obviously high P value was requested of the applicants and in reply a cablegram was received which stated:

> "Br13 only transcribing mistake Stop Fertig analyse should read correctly 0.0096 Stop Similar mistake was made in pig iron analysis in Br26 Stop Fact that in both cases third decimal missing while all other figures in same column contain three decimals proves that only transcribing mistake is involved Stop"

A corroborating affidavit by Hubert Hauttmann is enclosed also.

It is submitted that new claims 17 and 18 properly define the invention and are of a scope commensurate with the invention. Claim 17, the only independent claim, brings out quite clearly the fact that the stream of oxygen is discharged vertically downwardly against the surface of the bath without material agitation of the bath by the oxygen stream and that contact of the oxygen with the bath results in a reaction in a localized reaction zone spaced a substantial distance from the refractory lining of the vessel containing the molten iron. Further, the claim asserts that these new conditions result in the refining of the iron and gas evolution and in the production of high temperature in the reaction zone *away*

from the refractory lining. The reaction in the reaction zone produces a circulatory movement in the molten metal which brings those portions of the molten metal bath remote from the reaction zone into the reaction zone to refine those portions with minimum injury to the refractory lining.

It will be appreciated that the conditions of the reaction and for practicing the method are very different, indeed, from anything shown in the prior art and particularly the process disclosed in the Miles et al. French patent.

Accordingly, it is respectfully urged that the application is now in condition for allowance with claims 17 and 18, the only claims remaining therein.

Respectfully submitted,

BRUMBAUGH, FREE, GRAVES & DONOHUE
Attorneys for Applicants

PX-2A, pp. 78-84.

Rinesch Affidavit Filed June 11, 1957

[PX-2A, pp. 78-84]

IN THE UNITED STATES PATENT OFFICE

Applicant: Theodore E. Suess et al
Serial No.: 547,233
Filed: November 16, 1955 **Div. 3**
For: METHOD OF CARRYING OUT MELTING PROCESSES

AFFIDAVIT

I, Rudolf Rinesch, herewith declare and affirm that I studied metallurgy at the Montanistische Hochschule Mining College in Leoben and was graduated in automn 1938; that I have had twenty (20) years of practical experience in the manufacture of steel, based on practical and managing activity in various steel manufacturing enterprises; that from July 1, 1938 on I worked in the plants of VEREINIGTE OSTERREICHISCHE EISEN—UND STAHLWERKE as development engineer and later on as technical leader of the steel plant; and that I made a dissertation to obtain the doctor grade at the Montanistische Hochschule Mining College in Leoben concerning "The Evolution of the Oxygen Blowing Process"; and that I, Theodor S. Suess (deceased), Hubert Hauttmann and Herbert Trenkler are the joint inventors of the method described in United States application Serial No. 547,233.

I and Messrs. Suess, Hauttmann and Trenkler started our experimental work on manufacturing steel from crude iron by blowing pure oxygen on the surface of melted crude iron in June, 1949. At that time, we were aware of the state of technology as reflected in

the methods now described in German patent No. 735,196 to Schwarz and French patent No. 933,098 to Miles et al.

The two above-mentioned patents disclose blowing oxygen into a bath of melted crude iron from above and providing the oxygen jet with sufficient energy to cause it to penetrate deeply into the bath. The patentees intended to cause the reaction of the oxygen with the crude iron to take place within the bath. Information is not given in the patents about the composition of the crude iron or the analysis of the converted steel, or durability of the refractory lining of the converter and such information was not available to me and Messrs. Suess, Hauttmann and Trenkler at the beginning of our work.

Starting on the basis of the information available in 1949, we tried to manufacture steel from crude iron by blowing oxygen into the bath at a velocity sufficiently high to cause it to penetrate deeply below the surface of the melt. After a few preliminary experiments, we started on June 17, 1949 with a two-ton converter which was charged with crude iron containing 3.8 to 4.0 % C, 1.2 to 1.4 % Si, 1.6 to 1.8 % Mn, 0.12 to 0.17 % P, and approximately 0.03 % S. The bath depth was 500 mm. Bottled oxygen was used as an oxygen source. In order to achieve deep penetration of the bath with the oxygen stream, we employed a Laval nozzle of 8 mm diameter which was arranged approximately 10 cm above the surface of the bath. Oxygen was supplied to the nozzle at a pressure of 8 atmospheres gauge. A Laval nozzle was used for the reason that such a nozzle can discharge oxygen at supersonic speed and the jet of oxygen penetrated deeply into the melt.

PX-2A, pp. 78-84.

An analysis of the crude iron and the slag was made prior to blowing and during the blowing, the temperature was measured several times, the oxygen consumption was measured and finally, analyses were made of the final steel in the converter and after pouring into the ingot mold. All these values are reflected in the attached table identified as Exhibit "A". The experiments made with the Laval nozzle are identified by the annotation "Laval" in column 43 of Exhibit "A".

To our surprise, the tests made with a deeply penetrating oxygen jet did not give satisfactory results. The steel produced with the deeply penetrating blast contained between about 0.10 and 0.13 % phosphorous. Moreover, the lining of the converter was eroded quickly so that considerable quantities of MgO were released from the lining. MgO, as is generally known, causes a slag to react slowly and the slag was unable to absorb FeO which, in its turn, is needed for good dephorphorization. Indeed, a disproportionately higher proportion of FeO is dissolved in the bath so that the iron which is obtained is brittle and cannot be used for rolling and drawing.

The experiments employing a deeply penetrating oxygen stream made us realize that deep penetration of the bath by the oxygen jet must be avoided, if we were to obtain a high quality iron or steel and at the same time, have a satisfactory operating life for the lining of the converter. For that reason, our subsequent experiments were conducted with a normal or cylindrical nozzle through which the oxygen stream was discharged at approximately 280 m/sec. The spacing of the nozzle from the bath was adjusted so that the force of oxygen

blast on the melt surface was controlled and the jet did not penetrate appreciably into the molten bath. As indicated in Exhibit "A", we changed over to a normal nozzle on June 22, 1949. However, we still used the converter which had been eroded by the preceding experiments so that the slag used at that time had too high a MgO content. The converter was relined and other experiments were started on June 25, 1949. Using crude iron of the same composition as that described above, steel was obtained having an analysis within the limits sought by us: carbon below 0.1 %, and phosphorous below 0.05 %, mostly between 0.01 and 0.03 %. An occasional experimental run did not give the expected results, but the majority of the experiments thereafter were successful because we had now determined that a satisfactory refining operation could be obtained so long as the oxygen jet does not penetrate deeply into the bath.

The composition of the slag resulting from the successful experiments shows that the MgO content was below 10 % and that the iron content of the slag increased to an average of 14 to 20 %. Such a slag forms with limestone a very fluid, lime-ferrite slag which absorbs the phosphorous as shown by the fact that it contains an average of 1.2 to 1.8 % P_2O_5, as compared with 0.18 % to 0.3 % P_2O_5 in the slag which was formed by the deeply penetrating oxygen stream.

The success of our experiments grew out of a departure from the methods disclosed in the Schwarz and Miles et al. patents, which were developed for Brassert & Company while the patentees were employed by that company. I know that attempts were made to manufac-

ture steel in accordance with the patented methods in Italy and that such attempts were not successful.

On the basis of our successful experiments, an attempt was made to determine the reason for the differences in the results obtained by our method over the results obtained with the patented methods. As an essential characteristic of our method, I consider the fact that, by our method, a limited center of reaction is created in the surface layer of the bath by blowing oxygen onto the surface through a nozzle which is placed at a considerable vertical distance from said surface. If these conditions are observed, the basic requirements for the course of the reaction as conceived by us are present. In the aforementioned center of reaction, oxygen reacts with iron and with the elements accompanying the iron, such as silicon, manganese and carbon. Thereby, a slag is created which is rich in oxides and heat is set free. This center of reaction is hotter than the rest of the bath and the reaction velocity is very high therein. The iron which in the field of reaction was freed from the elements accompanying it has a higher density than the crude iron and sinks to the bottom of the converter. This movement is aided by evolution of gas so that the molten iron begins to circulate in the converter. The fluid and light slag, together with CO formed during the reaction, cannot rise from the bath against the impact of the oxygen stream, and are diverted away from the field of reaction and towards the outer edge of the bath. The iron oxide in the slag reacts with the carbon which is still present in the melt and consumes heat so that those parts of the bath which are outside the field of reaction are cooled off and the

erosion of the converter lining is correspondingly reduced. The circulatory movement of the molten bath causes automatic self-deoxidation of the bath due to movement of the oxiderich portion of the bath into contact with the un-oxidized portions of the bath, until the desired purification has been obtained.

The above explanation indicates that a steel of satisfactory purity cannot be obtained with a method utilizing a deeply penetrating oxygen stream. Such a deeply penetrating stream creates an uncontrollable turbulence in the bath. The oxygen remains dissolved in the bath and the high oxygen content in the final steel leads to hot shortness or requires unsatisfactory quantities of deoxidizers. Furthermore, the phosphorous cannot be slagged off. Moreover, the walls, and particularly the bottom of the vessel become as hot as the reaction center and, therefore, are eroded severely.

The success of our method is shown by the fact that since 1949 almost two million tons of steel has been produced in accordance with our method at the plant of affiant's assignee and recently, the plants using our method have been expanded to give a yearly output of one million tons. Throughout the world a capacity of about ten million tons is installed or being installed.

I believe that United States applications Serial No. 206,147 and Serial No. 547,233 clearly discloses our method and the novel and essential details thereof. The important feature of the invention resides in controlling the force of the oxygen jet vertically impinging on the bath surface to cause a limited center of reaction to be created in the surface layer and to avoid deep penetration into the bath, whereby an automatic circulatory

movement is obtained in the converter vessel, and the entire charge is refined by the oxygen molten metal reactions in the limited center and the slag-metal reactions in the bath surrounding the reaction center.

I believe that the disclosure of the United States application is sufficient to enable the man skilled in the art to determine the type and dimensions of the nozzle, the oxygen pressure and the distance between the nozzle and the bath for any specific type or size of converter so that an adequate amount of oxygen is supplied to the converter while avoiding deep penetration of the bath.

Inasmuch as our concept of avoiding deep penetration of the molten metal with the oxygen blast is just the opposite of the methods disclosed in the Schwarz and Miles et al. patents and constitutes a major technical advance in the manufacture of steel from crude iron, I believe that our method is patentable,

FRANZ RUDOLF RINESCH

PX-2A, pp. 88-92.

Hauttmann Affidavit Filed June 11, 1957

[PX-2A, pp. 88-92]

IN THE UNITED STATES PATENT OFFICE

Applicant	:	Theodor E. Suess et al
Serial No.	:	547,233
Filed	:	November 16, 1955 Div. 3
For	:	METHOD OF CARRYING OUT MELTING PROCESSES

AFFIDAVIT

I, HUBERT HAUTTMANN, being sworn, declare that I studied at the Technical College, Vienna and the Mining College, Leoben, and I obtained my engineering degree in 1921 and my doctor's degree in December 1942;

I have been a lecturer at the Mining College in Leoben since 1950;

I have had more than thirty-five (35) years of experience in the field of research and testing of mining and smelting products of all kinds, particularly steel, and that I have been active in the steel industry for aproximately forty (40) years;

Since January, 1948, I have been a director of VEREINIGTE OSTERREICHISCHE EISEN - UND STAHLWERKE where I manage the Testing Institute and the Research and Quality Control Department; and

I am one of the inventors of the method disclosed and claimed in U. S. patent applications Serial Nos. 206, 147 and 547,233; Theodor E. Suess (deceased), Her-

PX-2A, pp. 88-92.

bert Trenkler and Rudolf Rinesch are joint inventors of the method described in U.S. patent applications Serial Nos. 206,147 and 547,233.

The technological conditions as expressed in the Schwarz German patent No. 735,196 and Miles French patent No. 933,098 which make conversion of crude iron to steel conditional upon the deep penetration of the oxygen stream into the bath, were known to me prior to 1949. The patentees intended the oxygen to be carried to all parts of the bath by the agitation or stirring produced by the deep penetration of the bath by the oxygen jet. Thereby the reaction of the oxygen with the crude iron was intended to take place within and throughout the bath by the oxygen seeking out the impurities. Furthermore, through Lellep's tests at the Gutehoffnungahütte, Germany, I was familiar with the effect of pure oxygen in the interior of a bath, although in those tests the oxygen was blown into the bath from the bottom. In view of the fact that in accordance with known technology prior to 1949, nobody had as yet succeeded in carrying through a commercially satisfactory steel manufacturing method involving the blowing of molten crude iron from above with a stream of oxygen, Messrs. Suess, Rinesch, Trenkler and I started our work in 1949 on the development of a method of refining crude iron with oxygen by utilizing the conditions suggested by Schwarz and Miles. In order to assure penetration of the jet into the bath, we selected for tests on June 17, 1949, a Laval nozzle of about 8 mm, inside diameter which was arranged at a short distance, e.g., 10 cm. from the surface of the bath and an oxygen pressure of eight atmospheres gauge. After a few tests

conducted with a converter having a two-ton capacity, it became clear that deep penetration of the bath by the oxygen jet with agitation producing injury to the lining and its consequent interference with the refining action, must be avoided if we were to obtain a high quality iron or steel and, at the same time, have a satisfactory operating life for the lining of the converter. We then selected different blowing conditions whereby the stream of oxygen does not agitate or stir the bath materially. The new blowing conditions produced highly satisfactory steel and with a very substantial reduction of the erosion of the lining of the converter. An occasional experimental run did not give the expected results, but the majority of the experiments thereafter were successful because we had now determined that a satisfactory refining operation of the entire bath could be obtained so long as we relied mainly upon induced circulation due to a localized reaction center as distinguished from relying upon the stirring action of the oxygen jet penetrating deeply into the bath. While the advantages of the new method were appreciated at once, a completely satisfactory explanation for the improved results was not readily apparent. However, as the result of greater experience with the method as used in commercial production, I am convinced that an essential characteristic of our method is that a limited center of reaction is created in the bath by blowing oxygen onto the surface through a nozzle which is placed at a considerable vertical distance from said surface, said center of reaction being spaced laterally from the side walls and vertically above the bottom wall substantially in the surface layer and that agitation such as is caused by the deep penetration of the jet

according to the methods of the prior art, together with injury to the lining, and interference with the refining action thereby are avoided. Moreover, with the deep penetration method, more oxygen per unit of time per unit of surface area of the bath is furnished than the surface layer of the bath is able to absorb, with consequent reaction of the excess deep within the bath, while in our method the amount of oxygen supplied per unit of time per unit of surface area for elimination of the impurities does not greatly exceed the amount that the reaction center on the surface layer of the bath can absorb.

Another difference between the method discovered by us and the prior method is that the force of the oxygen jet vertically impinging on the bath surface is controlled to avoid uncontrolled agitation or stirring of the bath whereby an automatic circulating movement is obtained in the converter vessel, and the entire charge is refined by the oxygen-molten metal reactions in the limited center and the slag-metal reactions in the bath surrounding the reaction center. As a result of the heat being generated by the burning of iron and the impurities in the reaction zone in the surface layer of the bath, completely different temperature conditions result as compared with the temperature conditions produced by blowing the oxygen deeply into and stirring the molten metal with the oxygen jet. When the reaction takes place deeply within the bath, the heat generated raises the temperature of the metal generally and it and the highly heated gases are brought violently into contact with the refractory lining. Thus, the temperature difference between the center of the reaction

and the remainder of the bath is substantially less than in our process where the reaction takes place principally in a zone in the surface layer of the bath, creating a very high temperature near the slag to promote an early fluid slag and also resulting in lower metal temperature in the other portions of the bath which protects the lining thereby avoiding the injurious effects brought about by deep penetration of the bath when following the methods taught by the prior art.

Inasmuch as our concept of securing purification of the entire contents of the bath mainly by the controlled circulation induced by the reaction center is just the opposite of trying to carry the oxygen to all parts of the bath by agitation produced by deep penetration, as by the methods disclosed in the Schwarz and Miles patents, and constitutes a major technical advance in the commercial manufacture of steel from crude iron, I believe that our method is patentable.

HUBERT HAUTTMANN

DX-61, Tab 8.

Translation of Schwarz German Patent No. 735, 196, Published July 3, 1943

[DX-61, Tab 8]

[Agreed Translation Nov. 30, 1962]

GERMAN REICH
PATENT OFFICE OF THE REICH
PATENT NO. 735,196
Class 18 b Group 8
B 187456 VIa/18 b

Inventor: Dr. Carl Schwarz of Berlin.

Applicant: H. A. Brassert & Co. of Berlin-Charlottenburg.

METHOD OF TREATING LIQUID BATHS, FOR INSTANCE METAL BATHS, WITH GASES

Patented in the German Reich as from May 24, 1939.

Allowance of the patent made known on April 8, 1943.

Pursuant to Article 2, Paragraph 1 of the Ordinace of July 20, 1940, the declaration has been submitted that the protection of the patent is to extend to the Protectorate of Bohemia and Moravia.

Published on July 3, 1943.

If liquid baths, for instance metal baths are to be treated with gases, it is important to bring the reactants into as intimate contact with each other as possible. Surface contact is not sufficient in most cases to produce a rapid reaction, such as the blowing of the gas over the surface of the bath or the mere blowing of the gas onto the surface of the bath. The blowing of the gas

through the bottom or wall of the container and the bath or the blowing of the gas into the bath by means of a pipe naturally results in substantially stronger contact of the reactants and thus a substantially faster reaction, but in many cases it cannot be employed for technical and practical reasons.

The object of the present invention is a method of bringing gases into particularly intimate contact with liquid baths, for instance metal baths, by providing the jet of gas directed onto the surface of the bath with such a high kinetic energy that it is capable of penetrating in the manner of a solid body deep into the bath by the use of extremely high velocities lying preferably above the speed of sound. In this way it is possible, without any addtional means, such as for instance a pipe or the like which is subject to rapid wear, to cause the jet of gas to act within the liquid baths so that the reaction takes place extremely rapidly and completely.

In the converter process, to be sure, it is known to use a high blast inlet velocity, possibly of a speed lying above the speed of sound, in order to conduct the air through the bath in as compact a jet as possible. Since in this case, however, the blast is introduced into the bath from below through the converter bottom, it was not possible to obtain from this proposal the idea, when treating liquid baths, for instance metal baths, with gases, to cause the jet of gas to impinge on the surface of the bath with such a high velocity that it was capable of penetrating into the bath in the manner of a solid body.

Nor is it any longer new to introduce liquid alkali compounds in the form of a thin stream under the action of high pressure vertically or obliquely into a metal bath. From the fact that a liquid jet can be imparted such a high velocity that it penetrates into a metal bath, it could, however, not be concluded by far that it would also be possible to conduct a jet of gas from above in such a manner onto a liquid bath that it was capable of penetrating into the interior of the bath.

This manner of procedure can be employed, however, with particular advantage in metallurgical processes, for instance for the treatment with gases of molten metals or slags. Thus, for instance, liquid blast furnace or other slags can be treated in the manner described with air, oxygen-enriched air or oxygen itself, in order to burn the sulfur and any other components which are still unoxidized, and thereby bring about a heating of the slag to higher temperatures. Further possibilities of use in the method in accordance with the invention consist of the blowing of carbon-containing gases into metal melts to effect carburization, or the blowing of steam into iron or steel melts, in order to effect so-called water-refining.

The method in accordance with the invention is particularly suitable, however, for the refining of iron and steel melts, and as a matter of fact, preferably with the use of oxygen-enriched blast or oxygen. In the refining of iron and steel melts one can, it is true obtain relatively high reaction velocities by the air blowing process in which air is blown through the wall of the vessel and the liquid bath. Even in the ordinary wind blowing process, however, the blowing bottom is that

part of the wall of the vessel which becomes most rapidly worn. When using oxygen-enriched blast, the action on the blowing bottom, due to the large local overheating and accumulation of ferrous oxide is even greater, so that the possible enrichment with oxygen finally finds a limit due to the excessively short life of the blowing bottom. In the case of laterally blowing converters, in which the blowing nozzles lie deep below the blowing surface, similar disadvantages occur. When the blowing holes are located only just below the surface of the bath or even above it, the disadvantage of excessive wearing of the bottom recedes, it is true, but on the other hand the utilization of the blast is extremely poor. Furthermore, there is frequently the drawback in this case that the wall lying opposite the blast inlet is too strongly attacked by the gases or by a flame formed by the gases.

In the refining of steel with oxygen-enriched air or oxygen, when using the method in accordance with the invention, the danger of rapid wear of the container liner is eliminated since the reaction between oxygen and iron or iron-accompanying substances with the phenomena resulting therefrom, namely local overheating and accumulation of ferrous oxide, takes place in the center of the steel bath and therefore the walls of the vessel are not substantially attacked. Accordingly, the invention for the first time makes possible in actual practice the use of very strongly oxygen-enriched blast or oxygen for the refining of steel. Refining with oxygen, however, results in exceptional advantages, namely the speed of refining or decarburization of steel melts can be very considerably increased and the thermal balance of the process becomes so favorable that one is not

restricted to furnaces in order to carry it out, but can carry it out just as well in unheated containers, and can utilize the excess heat for the melting down of scrap or for other purposes.

The method in accordance with the invention can also be used in the manner that pulverulent solids are introduced into the liquid bath by means of gases, a good distribution of these substances being thereby obtained, particularly in case of varying direction of the jet. The gas can in this case exert an action of its own on the liquid bath, but may also serve merely as vehicle and carrier for the solids.

Claims

1. Method of treating liquid baths, for instance metal baths, by gases directed against the surface, characterized by the fact that the jet of gas which is directed against the surface of the baths has such a high kinetic energy that it is capable of penetrating deep, in the manner of a solid body, into the liquid baths.

2. Method according to Claim 1, characterized by the fact that the jet of gas which impinges with high kinetic energy on the surface of the bath and penetrates into same serves as vehicle and carrier for solids which are to be introduced into the baths.

DX-61, Tab 9.

Translation of Miles Belgian Patent No. 468,316, Granted November 30, 1946

[DX-61, Tab 9]

[Agreed Translation November 2, 1962]

KINGDOM OF BELGIUM
MINISTRY OF ECONOMIC AFFAIRS
AND MIDDLE CLASSES

PATENT NO. 468316

Application filed on October 4, 1946

Patent granted by Ministerial Decree of November 30, 1946

SPECIFICATION
filed in support of an application
for
Patent of Invention
by
John Miles & Partners (London) Limited
for

IMPROVEMENTS IN METHODS OF REFINING METALS

British Patent Application of May 3, 1945, in the name of John Miles and British Patent Applications of June 15, 1945, and January 4, and 11, 1946.

The present invention relates to the refining of both ferrous and non-ferrous metals.

Many impurities which are present in metals are normally eliminated by oxidation when the metal is melted and air or oxygen is brought into contact with

the impurities so that they are eliminated in gaseous state or in solid state in the form of slag. The conversion of cast iron into steel is an example of this known process and the present invention, although not exclusively limited thereto, can be applied with particular advantage to such a method of refining.

In accordance with the invention, the refining process consists in injecting into the molten metal, by a blast, an oxidizing fluid at such speed that a sufficient proportion of the fluid penetrates into the metal to react there on the oxidizable impurities and eliminate them from the metal and this process is characterized by the fact that the fluid employed contains not more than 30% nitrogen and a quantity of oxygen between 70% and 98%.

The mixture of oxygen and nitrogen may be a gas or a liquid, each of them having its own advantages. Thus, for instance, one of the advantages afforded by the use of a liquid instead of a gas for the jet is that the liquid has a greater force of penetration into the metal; if desired, therefore, the projecting tuyere can be maintained at a greater distance from the metal. Another advantage results from the fact that the oxygen-nitrogen mixture is produced in liquid state during normal manufacture and can be transported and stored more economically than a gas.

The oxygen-containing fluid can be projected from top to bottom onto the surface of the metal to be treated at such speed that the major part of the fluid jet penetrates into the bath. The velocity of the fluid at the surface of the metal required to cause this substantially complete penetration must necessarily vary in accord-

ance with the circumstances in each case. In particular, it varies as a function of the viscosity and the density of the metal to be treated. It has been found, for instance, that a nozzle of 0.32 inches inside diameter, the tip of which is 6 inches above the surface of a bath of molten cast iron requires a gas pressure of 7 or 8 atmospheres to deliver about 10,000 cubic feet of gas per hour into the bath at a speed of about 1250 feet per second, this speed being obtained by a suitable profile of the nozzle. The speeds of this order of magnitude are desirable in order to obtain an optimum penetration and effect of the fluid, but lower speeds can be used, giving rise to a corresponding reduction of the oxygen production. The oxygen which is thus reflected can be used to burn the combustible gases produced, such as carbon monoxide, thus producing additional heat.

The high speed of the fluid jet has the effect that the source of chemical oxidation reactions is located within the bath at a good distance from the refractory lining of the furnace. These reactions are ordinarily exothermal, the heat developed being frequently the only heat necessary to maintain the metal at the desired temperature and fluidity. The fact that the reactions take place in the interior of bath assures the use of the developed heat to the maximum degree. Furthermore, the expansion of the gas as it leaves the nozzle serves to maintain the nozzle cold. The penetration of the jet also fulfills the useful function of agitating the bath so that the reactions take place uniformly and to the maximum extent. The course of the refining can be controlled by varying the inclination of the jet with respect to the surface or by varying the velocity of the gases or their composition.

One of the greatest difficulties which has been encountered up to the present time in the refining of metals by causing a relatively feeble current of air to pass through the metal is that the nitrogen and sometimes the hydrogen are absorbed and remain in the metal at the end of the refining operation. It has already been proposed to overcome this difficulty by using pure oxygen, but this idea has never been applied on a large scale due to the relatively high cost of pure oxygen.

However, it has now been found that if the fluid jet projected at high velocity into the metal is formed of oxygen which does not contain more than 30% nitrogen, practically none of said latter gas is absorbed by the metal. On the other hand, it has been found that it is too costly to employ a fluid containing more than 98% oxygen so that in effecting the present invention, the relation of nitrogen to oxygen in the refining fluid has been kept between 30/70 and 2/98.

The preferred percentage of nitrogen is between 5% and 25% and at the present time the cost of oxygen which contains this percentage of nitrogen is relatively low and does not prevent the industrial application of the invention.

If the invention is employed to convert cast iron into steel, air can be employed during the first part of the conversion operation until approximately half the carbon content has been oxidized, the blowing being terminated with oxygen which does not contain more than 30% nitrogen, in order to produce carbon monoxide bubbles which, upon rising through the metal, entrain all the nitrogen present in the metal or retained during the first part of the blowing.

The invention can be applied in various manners to the known Bessemer process, thus, for instance, in the customary basic Bessemer, the blasting can be effected until the end of the carbon flame period after which the converter is tipped downward, the air feed is cut off and a high speed jet of oxygen and nitrogen in liquid or gaseous state is projected in order to oxidize the remaining impurities, the liberation of heat being obtained in the customary manner. The jet is caused to penetrate the surface of the bath of molten metal in one or the other of the manners described above.

In accordance with a variant, the normal blasting of the Bessemer can be prolonged until the major part of the phosphorus has been eliminated, whereupon the converter is tipped from top to bottom, the slag is removed and a new quantity of carbon is added, in particular by the addition of cast iron or metal from the mixer; lime is added and, if desired, other fluxes, and the blasting is then continued for a few minutes with an oxygen-nitrogen jet of high speed so as to obtain a steel having a low nitrogen content. The processing of the steel is then continued until the desired composition is obtained by the addition of ferro-manganese, spiegel, aluminum, etc.

One or the other of these modifications in the Bessemer process leads to a steel, the nitrogen, sulfur and phosphorus contents of which are comparable to those from the Martin furnace or of electric steel.

The jet can be introduced into the molten metal either through the spout of the converter or through one of the tuyeres, whether the latter are contained in the bottom or in the sides of the converter. In the case

of a bottom-blown converter, a door can be provided in the bottom plate which is opened after the converter is tilted downward in order to permit the jet to pass through the tuyere holes.

It has been found that when the Bessemer process is modified from normal by the incorporation therein of the present invention, in other words when the normal blowing is replaced by a high speed jet of oxygen containing not more than 3% nitrogen, the phosphorus is substantially completely eliminated before the total elimination of the carbon. It follows that the modified process has the very great advantage of avoiding the necessity of recarburizing the metal at the end of the blowing. It becomes needless to provide the Bessemer with the usual bottom if the high speed jet is injected into the bath of molten metal through one or more tuyeres, the nozzles of which are located a few inches above the surface of the metal bath. In the known process, the nitrogen which passes through the bath absorbs a large part of the heat liberated, but in accordance with the present invention, as the quantity of nitrogen is very greatly reduced, there is a great saving in heat. The reactions are produced much more rapidly, which makes it possible to obtain higher temperatures. It follows that the process can be applied to the conversion of crude metals containing much smaller proportions of heat-liberating elements, such as silicon, carbon and phosphorus. As a variant, or in addition, the process can be used for crude metals containing much higher percentages of turning or cuttings in view of the fact that, as indicated above, nitrogen is not introduced into the metal and obviously no hydrogen since there is none in the jet.

In the manner in which converters operated up to the present time, it was not possible to add to the charge more than 5% scrap or other operating waste, although approximately 25% of the steel ingots obtained by this process come from the plant in the form of waste. It would be extremely advantageous for a self-sufficient plant to use all its own waste and that the present price of steel scrap, which is less than one-half that of cast iron, an even higher percentage of waste constitutes a further important advantage.

Therefore, another object of the invention is to provide a process for oxidizing the impurities contained in the metals which is not limited, as up to the present time, by the relative quantities of heat-generating elements in the crude metal, so that the process presents great flexibility in the sense that it can be used for charges where the relation of scrap to cast iron varies considerably, and the iron compositions of which are extremely different with respect to the above-mentioned heat-generating elements.

This purpose is obtained by adding to the bath either continuously or intermittently, while the jet is penetrating a heat-generating element, such as carbon.

This special process can be carried out in a closed furnace, with refractory linings, tilting or rotating and provided with outlets at its two ends for the escape of the gas burning above the metal. At each end, there are also provided one or more nozzles by means of which a mixture of nitrogen and oxygen can be projected at high velocity into the bath of molten metal resting on the hearth of the furnace. The cross-section

of the hearth is preferably elliptical or oval, its major axis being vertical and perferably longer than its horizontal axis, since this form has the advantage of giving rise to a roof or crown of relatively small span so that the charging can be effected from above, and therefore both the front and rear walls of the furnace may have a slope which is at present generally true only of the rear wall of the conventional type of Martin furnace. The hearth is provided at each end with a single regenerator through which the burned gases are circulated and in which the entering air for the combustion is heated. The reversal is effected at suitable intervals which, depending on the speed of the operation, may coincide with the charging.

The furnace is charged at the start with molten metal such as cast iron containing a relatively high proportion of carbon and/or other heat-producing elements, or else said metal may be melted in the furnace, after having been charged, by gas burners. By means of nozzles at one of the ends of the furnace, there is projected into the bath of molten metal a jet of fluid consisting preferably of a mixture of 10% nitrogen and 90% oxygen. The jet is directed from top to bottom upon the surface of the metal at a velocity which is sufficiently high to assure the penetration of almost all the fluid into the bath. The jet serves to maintain a vigorous agitation so that the oxidizing reactions follow one another in the interior of the bath at a very high speed and with a very high chemical yield of oxygen.

The silicon and the phosphorus pass into the slag while the carbon burns, producing carbon monoxide, which rises above the metal and the slag where it burns.

being converted into carbon dioxide with the air or oxygen or mixture of oxygen and nitrogen admitted at the inner end of the furnace. All of these reactions are exothermal and supply a part of the heat necessary to maintain the operation going. The scrap is charged into the furnace between its center and the outlet end during the blowing period.

The oxygen-nitrogen jet, together with a suitable slag removes a large portion of sulfur so that the direct addition of coal, coke or other carbonaceous material to the bath becomes possible. However, it is preferable that the carbonaceous material contain only a small amount of sulfur and volatile substances.

The carbon may be added to the bath, either continuously or intermittently and in quantity sufficient to supply, by its oxidation, the heat necessary to maintain the operation and melt the scrap added. The carbon added to the bath may come from a "massive electrode" of the Soderberg type which penetrates into the furnace through the roof at the end opposite the inlet end and consists of a carbonaceous material such as anthracite or coke, bonded by pitch or other similar substance arranged in a steel sheath and protected on the outside by a refractory lining. This electrode can be raised or lowered as desired through a water-cooled opening in the top of the furnace. In accordance with a variant, the carbon may be added to the bath in the form of pulverized coal injected into the furnace at high speed either together with the oxidizing fluid or by separate nozzles. Or else it may be projected into the metal by a centrifugal machine of the sand-blast type. In either of these two latter cases, the carbon may be

added to the bath on the same side of the furnace as the jet, but when "electrodes" are employed, it is preferable to cause the electrode to descend into the bath at the outlet end of the furnace so that it does not interfere with the jet.

When the carbon is immersed in a bath of iron or steel, it is known that the rate at which the carbon dissolves is a function of the carbon content of the bath; it is extremely fast at low contents and very slow when the carbon content of the metal approaches 3%.

For reasons of the metallurgical art, it is desirable to have a purifying boil of carbon monoxide to remove all the gaseous impurities. It is therefore desirable, in view of these two considerations, to maintain the carbon content at about 0.6% to 1% for instance during the phase of operations during which the carbon is added to the bath. At this strength, the carbon dissolves rapidly and when the addition is stopped, a sufficient quantity of carbon remains in the bath to produce a finishing boil at the end and assure the required carbon content at the end of the operation. The above indicated value of 0.6% carbon can be decreased of course if steel of low carbon content is produced. The carbon content of the bath can be regulated by the degree of admission of oxygen, the degree of admission of carbon and the frequency of the tiltings if the circulation of the bath is slight.

If in certain phases of the operation the combustion of silicon or phosphorus alone is produced, then, of course, there is no advantage in permitting air to pass through the vents, the degree of admission of air being a function of the degree of production of carbon monoxide.

During the operation the slag is maintained in the desired conditions by the addition of lime, iron oxide, fluorspar, alumina, silica and other fluxes. The lime is preferably crushed first of all to sizes of 2" to 4" and the fines removed.

The production of metal can be increased and also the temperature of the bath regulated by the addition of iron ores and iron oxides. This method of adjusting the temperature can be employed when sufficient scrap is not available to assure an adequate control of the temperature.

After the melting of the entire charge and the blowing until the desired carbon content has been obtained, the steel can be completed in the customary manner by the addition of deoxidizing agents and alloy elements.

The high speed jet causes a vigorous agitation and an entrainment of the slag in the body of the metal, thus assuring an intimate mixing and rapid reactions.

The effectiveness with which the carbon monoxide liberated is burned to form carbon dioxide is considerably increased by the action of the regenerators which reheat the combustion air. The furnace must be designed to permit the gases to remain in the hearth for a sufficient period of time to assure complete combustion in the interior of the furnace chamber.

The air vents are preferably so made as to direct the stream of air from top to bottom toward the adjacent end of the bath and along the surface of the slag and the metal. The nozzles are placed either alongside the air vents or through them (or in both these positions at once) so that the jets strike the bath as near

as possible to the side of the bath on which the vents are. This arrangement permits the carbon monoxide produced by the combustion of the bath to be brought into immediate contact with the heated air. It may be advantageous to withdraw the oxygen pipes which are not being used.

If desired, the operation can be carried out in an annular furnace provided with a central vertical shaft in which the scrap is melted, high speed jets of a mixture of oxygen and nitrogen being directed into the molten metal which is collected in an annular hearth surrounding the central shaft at a level located below the lower end of the shaft.

The process can also be carried out in a Bessemer converter, in a Martin furnace, in an electric furnace, or any other suitable furnace, whether or not provided with recuperators.

It will be noted that the process which has been just described is very flexible with respect to the selection of the ratio of scrap to molten iron, which makes it possible to take advantage of the prevailing price of scrap or iron. Furthermore, the consumption of fuel for the production of a Martin steel is considerably reduced.

In any of the above processes, the oxygen-nitrogen mixtures can be preheated with or without the help of the heat lost from the gases liberated during the main reaction. Besides, or at the same time, the crude metal can be preheated. The operation can be carried out in an electric arc furnace or in an induction furnace, the crude metal being preheated electrically, in which case —in addition to the blowing—the steel can be finished

by heating under a deoxidizing slag. By this method, there can be obtained ordinary and carbon steels of the same quality as electric steels.

The heat can also be produced by suitable additions either to the jet or to the metal.

Thus one can blow in, with the jet, or by other means, such as a separate gas feed, a readily oxidizable element (metal or alloy), that is to say an element which has a high heat of oxidation, such as carbon, silicon, aluminum, calcium, magnesium or other metals or alloys. The purpose in this case is to increase the temperature locally where the jet strikes the bath so as to bring about the oxidizing action more rapidly. These materials are preferably added in finely divided state, for instance in the form of crushed shavings or powder. These additions may, if desired, be introduced into the bath otherwise than by means of the jet.

Furthermore, there can be blown into the metal simultaneously with the jet a gaseous or liquid fuel, such as coke oven gas, generator gas, weak gas, oil or tar. The additional gas or liquid must be so directed that it burns with a part of the oxygen coming from the jet so as to increase the temperature locally.

In either of the two cases last mentioned, higher temperatures can be obtained or else the additions of scrap can be made in a body, in separate charges or continuously, during the blowing operation.

Or again, the steel shavings can be melted in a cupola or other furnace, in contact with carbonaceous materials and the jet blown in subsequently, the carbon absorbed in the cupola or other furnace being used as fuel during the blowing of the jet.

The jet may be such that it supplies excess oxygen so that it burns the carbon monoxide produced by the oxidation of the carbon and converts it into carbon dioxide on the surface of the slag or metal, thus producing an additional heat which can be used to melt a larger quantity of steel scrap. This result can be obtained by adjusting the angle or the velocity of the jet so that the entire oxygen-nitrogen mixture does not penetrate the metal, the excess or "reflected" oxygen serving to burn the carbon monoxide given off.

Fluxes, such as lime, limestone, fluorspar, alumina and silica can be added in order to form a slag to remove or neutralize the silica, the phosphorus pentoxide and any other product of the oxidation. One can also use the process which consists of preparing an initial slag to eliminate the silica and manganese oxide, the titanium or vanadium oxides, to remove the slag and then prepare a second slag to eliminate the phosphorus. A double formation of slag may also be effected to obtain steel of low phosphorus or sulfur content.

The slag may be prepared in advance if desired.

In each of these cases, the oxygen of the jet reacts not only with the constituent elements of the metal but also with the slag, thus increasing the oxygen content of the latter and therefore the oxidizing reactions in general.

The jet is established at any angle between 15° and 90° with respect to the horizontal, but preferably between 30° and 75°, while the distance from the jet to the metal and/or the slag should be between 1 and 20 inches, preferably between 4 and 12 inches.

As the volume of the slag and metal increases—by the addition of scrap—the level of the metal changes and the jet is made adjustable so that it can be maintained at a relatively constant distance from the metal bath.

The cross-section of the jet can be non-circular and have for instance a rectangular or flattened shape if necessary.

The jet may be protected against splatterings and frothing of the slag or the metal by means of a refractory metal tube or by a plastic refractory casing. The nozzle and the tubing are preferably made of a substance capable of withstanding oxidation which may be a metal or a refractory clay.

Several suitable jets located in the furnace can be used simultaneously and if desired each of them can be given a vibrating motion so as to cover a larger surface of the bath.

The jet serves to circulate and agitate the metal and the slag, which is useful if alloy elements such as nickel or molybdenum are to be added, and it assures the uniformity of the composition and the temperature throughout the bath.

The process can be applied to the refining of metals other than iron, for instance to the mixtures used for the blowing of molten sulfide baths, known as mattes, such as copper/iron sulfides or copper/nickel/iron sulfides in which the main impurities to be eliminated are the iron and the sulfur.

The jet blowing process described above can be used jointly with other known steel production or refining processes. For instance the jet can be used to melt or

reheat crude metal and the Martin process or the acid or basic Bessemer process can be used to complete the refining of the metal. On the other hand, the Martin process or the acid or basic Bessemer process can be used to reheat the metal after which the jet is used to refine the metal. In the case of the Martin process, the treatment of the metal may be completed by withdrawing the jet and again using the Martin process.

Or again the normal electrical process can be employed for melting the charge, whereupon oxidizing jets of high speed are blown into the metal to effect the main refining operations whereupon one can effect the deoxidation and the desulfurization in the normal manner in the electric furnace.

The present invention can be employed in its application to the normal Martin furnace not so much to improve the quality of the steel as in order to make the process less costly. Thus the time taken up for the conversion in the Martin furnace can be reduced to a very great extent by the introduction through the charging doors or through the rear wall of the furnace of jets of high speed which project an oxidizing gas into the metal bath during the carrying out of the normal Martin process.

In the following claims wherever mention is made of the projecting of a jet of fluid onto the molten metal, this expression must be considered to include the case that the jet actually strikes the slag at the surface of the molten metal and acts on the metal by passing through the slag and reaching the metal and/or by renewing the slag so as to regenerate or increase its power to act on the metal.

CLAIMS

1. A process for the refining of molten metal by the projecting of an oxidizing fluid into the metal at a velocity such that a sufficient proportion of the fluid penetrates into the metal to react therein with the oxidizable impurities of the metal and eliminate them, characterized by the fact that the fluid employed does not contain more than 30% nitrogen and a proportion of oxygen between 70% and 98%.

2. A process according to Claim 1, characterized by the fact that the oxidizing fluid is a liquid mixture comprising principally oxygen and nitrogen.

3. A process according to Claim 1, characterized by the fact that the oxidizing fluid is projected onto the surface of the metal bath to be refined through a nozzle at a certain distance above the metal.

4. A process according to Claim 1, characterized by the fact that the fluid is projected into the metal at a velocity which is not less than 1250 feet per second.

5. A process according to Claim 1, characterized by the fact that the metal is first of all treated by an oxidizing fluid containing more than 30% nitrogen and the refining is completed by means of a fluid which contains not more than 30% nitrogen and a quantity of oxygen between 70% and 98%.

6. A process according to Claim 1, characterized by the fact that a heat-generating substance such as a carbonaceous material is added to the metal before or while the oxidizing fluid is projected into the metal.

7. A process according to Claim 4, characterized by the fact that the carbon coming from a rod of carbonaceous material immersed in the metal is added to the latter before the end of the refining.

8. A process according to Claim 1, characterized by the fact that the oxidizing fluid is used as vehicle to bring a heat-generating substance such as a carbonaceous material into the bath.

9. A process according to Claim 1, characterized by the fact that metal scrap is added to the metal during the blowing.

10. A process according to Claim 1, characterized by the fact that the metal into which the blowing is effected consists of steel scrap melted in a cupola so as to absorb carbon, or contains steel scrap which has thus been treated.

11. A process according to Claim 1, characterized by the fact that the refining is effected in a Bessemer converter.

12. A process for the refining of molten metal, characterized by the fact that the metal is subjected to a preliminary blowing in a Bessemer converter in the known manner and is then subjected to the blowing in accordance with Claim 1.

13. A process for the refining of molten metal, characterized by the fact that the metal is subjected to blowing in a Bessemer converter until the major portion of the phosphorus is eliminated whereupon the slag is removed, a new quantity of carbon and then of lime is added, and the metal is refined in accordance with Claim 1.

14. A process according to Claim 1, characterized by the fact that the metal is refined by the ordinary process in a Martin furnace modified by the addition of one or more jets of an oxidizing fluid which is projected into the metal within the furnace so as to increase the speed of the refining.

15. A process according to Claim 1, characterized by the fact that the refining process is carried out in an electric furnace and that the treatment of the metal is completed under a slag with application of electric heating.

16. A process according to Claim 1, characterized by the fact that the blowing is effected reversibly as in the Martin furnace, in a furnace having a blast nozzle and a recuperator at each end.

17. A process according to Claim 1, characterized by the fact that the refined metals are alloys of copper or copper-nickel, obtained by the melting of sulfide mixtures.

Brussels, October 4, 1946.

John Miles & Partners (London) Limited

By: Office Kirkpatrick, H. & C. Plucker Successors. Its Attorney.

PX-353

SUMMARY OF DEPTH OF INDENT (PENETRATION) DURING INSPECTION HEATS AT McLOUTH

(Reblow excluded)

Heat No.	Minimum Indent			Maximum Indent			Average Indent	
	Time		Ins.	Time		Ins.	Ins.	% of Average Bath Depth
	Min.	Sec.		Min.	Sec.			
89285	5	40	0.9	20	10	5.9	3.5	7.8
89296	4	10	0.5	25	45	8.8	4.4	8.9
99042	4	50	3.1	9	35	12.6	8.8	21.4
99054	4	50	3.4	13	05	12.5	8.8	19.5
A4208	8-11	—	nil	27	00	5.2	1.9	3.3
A4209	7	50	1.1	24	00	7.7	4.4	7.7
A5013	22	00	nil	30	00	9.1	4.8	7.6
A5022	7-10	—	nil	34	00	8.9	3.6	5.8
18999	6	20	2.9	25	30	12.5	9.1	16.5
19000	8	20	2.9	22	30	12.4	9.2	16.1
27596	11	30	1.1	34	30	13.0	6.7	11.3
28463	5	00	3.8	8	00	12.3	9.2	15.3

AVERAGE INDENT FOR ALL HEATS — 6.2 ins.

PX-353.

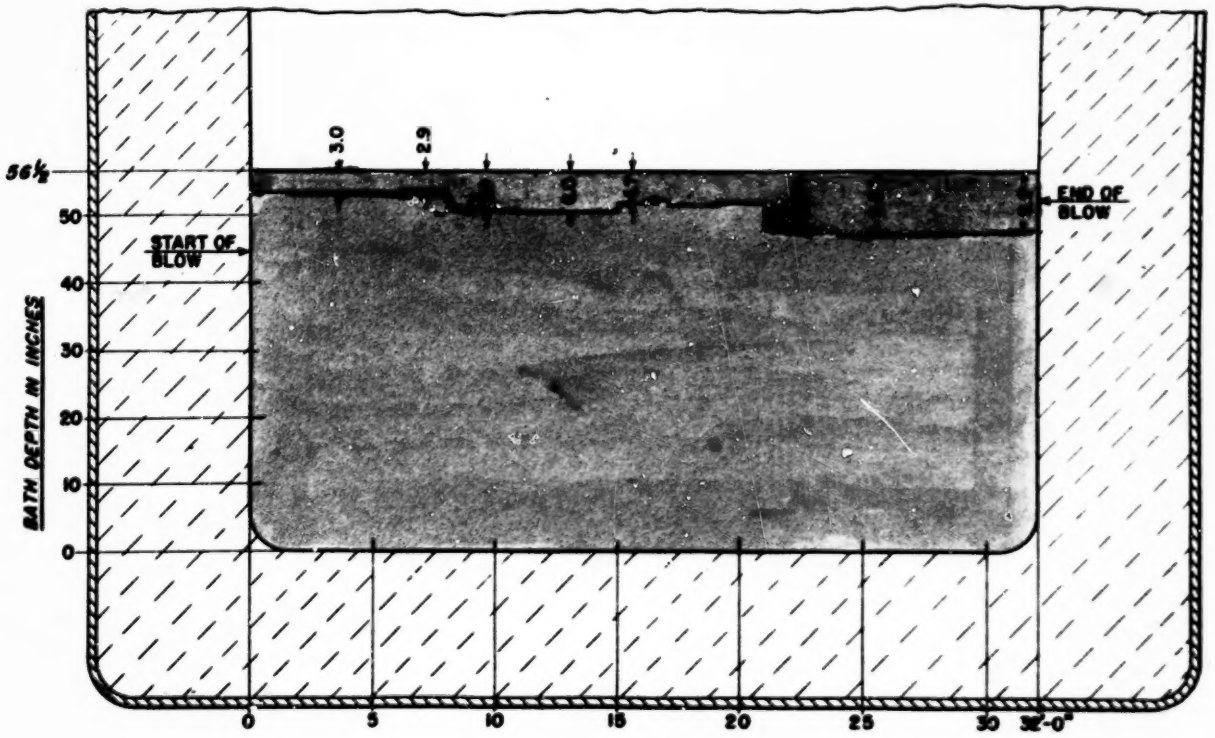
255a

KAISER et al. v. McLOUTH

PLAINTIFFS' EX. 332

PX-332.

Depth of Indent (Penetration)
Shown in Relation to Bath Depth and Time of Blow
McLouth Heat No. A-4209-March 13, 1961 - OP-2



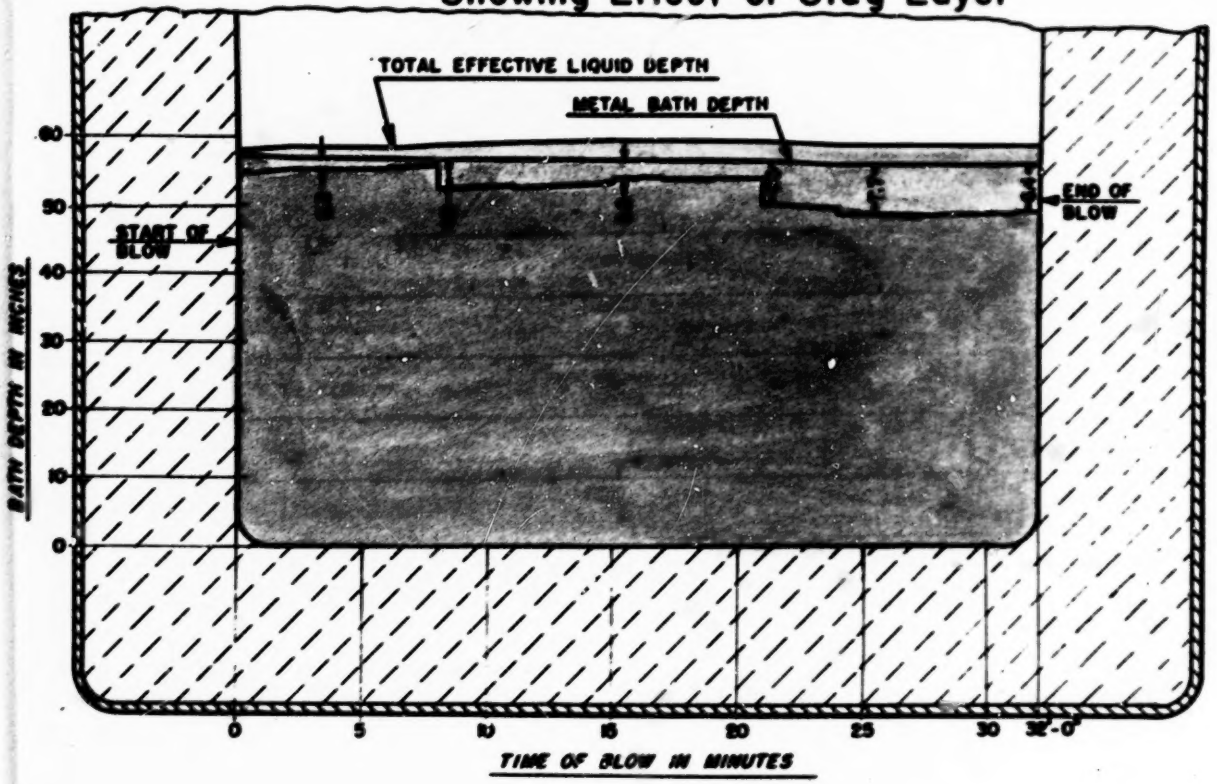
VIEW ILLUSTRATING "THE INDENT"

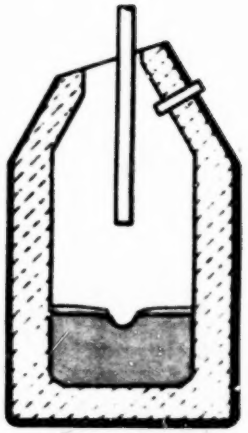
257a

KAISER et al. v. McLOUTH

PLAINTIFFS' EX. 351F

Depth of Indent (Penetration)
Shown in Relation to Bath Depth and Time of Blow
McLouth Heat No. A-4209—March 13, 1961—OP-2
Showing Effect of Slag Layer





VIEW ILLUSTRATING "THE INDENT"

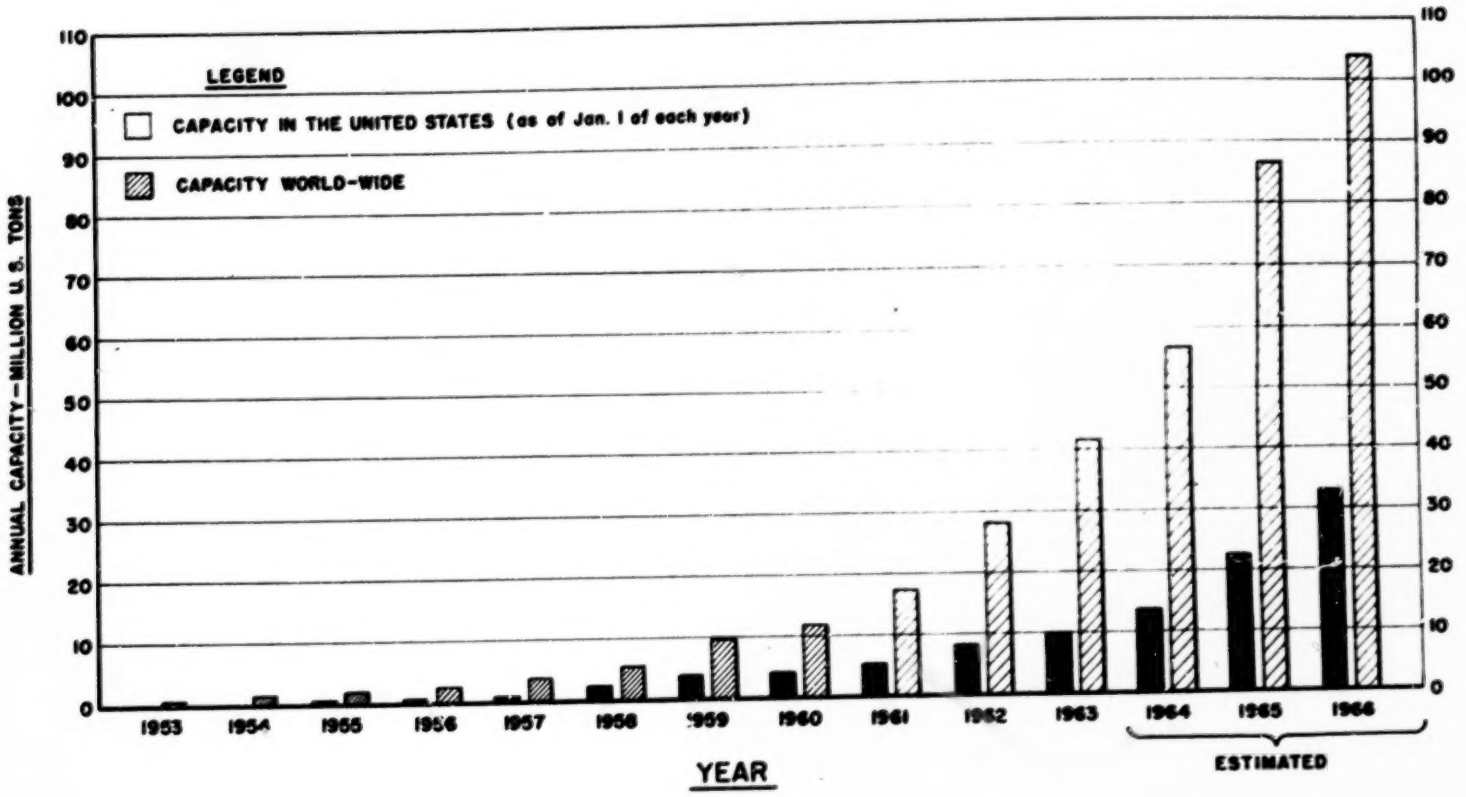
PX-351F.

259a

KAISER et al. v. McLOUTH

PLAINTIFFS' EX 82

L-D STEEL CAPACITY IN THE UNITED STATES AND WORLD-WIDE



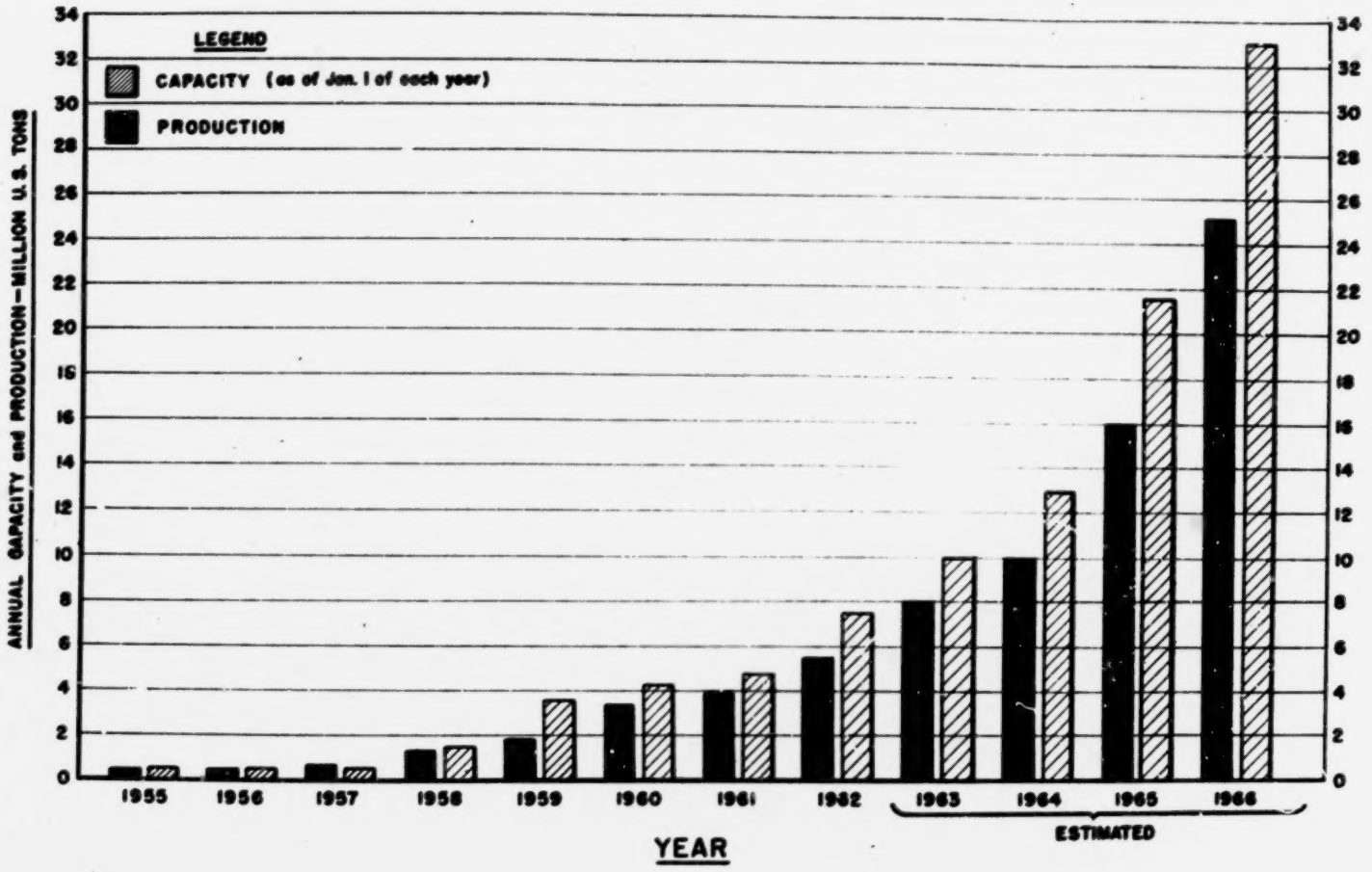
PX-82.

261a

KAISER et al. v. McLOUTH

PLAINTIFFS' EX 83

L–D STEEL CAPACITY AND PRODUCTION IN THE UNITED STATES



PX-83.

263c

PX-104.

L-D PROCESS NEWSLETTER

KAISER ENGINEERS DIVISION OF HENRY J. KAISER COMPANY • OAKLAND, CALIFORNIA

September 27, 1963
Newsletter No. 21

World-Wide Distribution of L-D Steel Plants

Annual capacity of L-D steelmaking plants in the United States has grown to 10 million tons, an increase of 33% from 7.5 million tons in July 1962. An additional three million tons is scheduled to go into operation by the first of next year, bringing total U.S. capacity to 13 million tons. By January of 1966, L-D plant capacity will have tripled today's tonnage, according to a recent survey by Steel Plants Development Department of Kaiser Engineers. At present, U.S. steelmakers are constructing 19 million tons of new capacity. This does not include plans of several other companies which could easily add 3 to 5 million tons to the 29 million ton figure projected for January 1966.

Use of the process for alloy steels as well as tonnage carbon steels is growing. Two companies have announced plans for using a significant portion of L-D production for alloy steels. Further, Republic Steel Corporation will be the first company in the United States to install a plant in the southern district. Their Gadsden, Alabama plant will be equipped to handle hot metal having phosphorus above the usual range used in this country.

Current production rates for L-D steel are running highe than those of the steel industry as a whole. Basic oxygen furnaces are operating at about 80% of capacity, compared with the industry operating rate of 70%. Cost advantages have had a large part in giving preference to L-D operations over open hearth. Current production figures indicate that 1963 basic oxygen production (including one Kaldo plant) will total about 8 million ingot tons, a 45% increase since 1962. This year's production will be slightly lower than that of the electric furnace's projected 11 million tons but should equal it in late 1964. Earlier predictions that L-D will equal open hearth production in the next decade still appear reasonable.

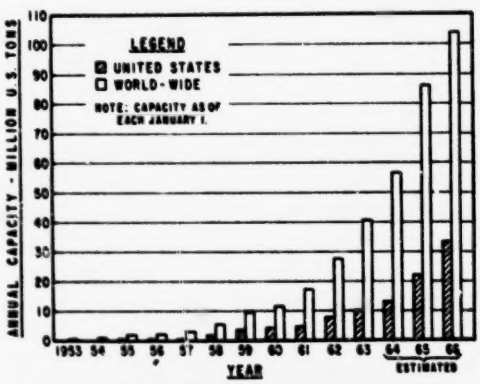
Steelmakers outside the United States are also increasing L-D capacity at a rapid rate. World capacity now totals 46.2 million tons, up 45% from July 1962. Future commitments indicate that world capacity will more than double by 1966 to over 100 million tons. The United States, Russia, West Germany and Italy will be major contributors to this future growth. The U.S. portion will climb from 25% to 32%. (See left graph on following page.)

In Europe, where high phosphorus hot metals are often used, lime powder injection techniques have been adopted in 13 plants and are planned in 12 more. European plants using Lorraine ores have pioneered this development. Japanese steelmakers have future plans to use the powder techniques.

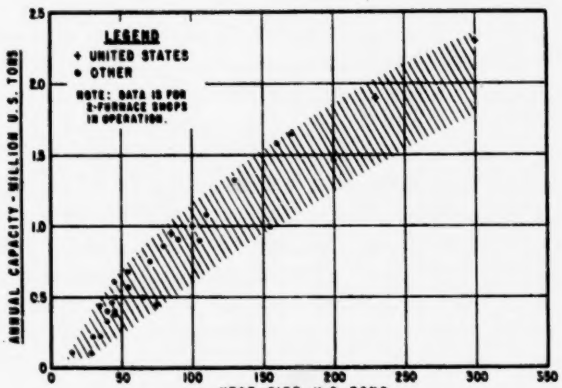
The listing of plants which follows indicates a trend toward large furnaces all over the world. The graph at the bottom right shows that the annual capacity of the operating plants reported increases almost in linear proportion to heat size. The spread of points, however, indicates the effect of raw materials, operating practices and product mix upon productivity.

J K Stone

J. K. Stone, Manager
Steel Plants Development Department



UNITED STATES AND WORLD-WIDE
L-D STEEL CAPACITY



EFFECT OF HEAT SIZE ON L-D PLANT CAPACITY

Company	Plant Location	No. of Furnaces & Output per Heat** (U.S. Short Tons)	Start-up Date	Annual Capacity** (U.S. Short Tons) Existing	Future Additions
UNITED STATES					
Acme Steel Co.	Riverdale, Ill.	2 x 75	1959	450,000	
Allegheny Ludlum Steel Corp.	Brackenridge, Pa.	1 x 20	1963		(Experimental)
Armco Steel Corp.	Ashland, Ky.	2 x 140	1963		1,400,000
Bethlehem Steel Co.	Lackawanna, N. Y.	2 x 250	1964/65		2,000,000
Colorado Fuel & Iron Corp.	Pueblo, Colo.	2 x 100	1961	1,000,000	
Ford Motor Co.	Dearborn, Mich.	2 x 240	1964		2,000,000
Great Lakes Steel Corp.	Ecorse, Mich.	2 x 300	1962	2,300,000	
Inland Steel Co.	East Chicago, Ind.	2 x 230	1965		2,000,000
Jones & Laughlin Steel Corp.	Aliquippa, Pa.	2 x 85	1957	950,000	
	Cleveland, Ohio	2 x 230	1961	1,900,000	
Kaiser Steel Corp.	Fontana, Calif.	3 x 110	1958	1,440,000	
McLouth Steel Corp.	Trenton, Mich.	3 x 60	1954)		
		2 x 105	1958)-	2,000,000	
		1 x 105	1960)		
Pittsburgh Steel Co.	Monessen, Pa.	2 x 150	1963		1,500,000
Republic Steel Corp.	Warren, Ohio	2 x 150	1965		1,500,000
	Gadsden, Ala.	2 x 150	1965		1,500,000
	Cleveland, Ohio	2 x 250	1965		2,000,000
United States Steel Corp.	Duquesne, Pa.	2 x 150	1964		1,500,000
Wheeling Steel Corp.	Steubenville, Ohio	2 x 225	1964		2,000,000
Wisconsin Steel Div. of International Harvester Co.	South Chicago, Ill.	2 x 120	1964		1,200,000
		TOTAL		10,040,000	18,600,000
ALGERIA					
Societe Bonoise de Siderurgie	Bone	3 x 65*	1965		990,000
		TOTAL			990,000
AUSTRALIA					
The Broken Hill Proprietary Co. Ltd.	Newcastle, N.S.W.	2 x 225	1962	1,280,000	
	Whyalla, S.A.	2 x 110	1964		560,000
		TOTAL		1,280,000	560,000
AUSTRIA					
Oesterreichisch-Alpine Montangesellschaft	Donawitz	2 x 35	1953	440,000	
Vereinigte Oesterreichische Eisen- und Stahlwerke AG	Linz	2 x 35	1952)		
		1 x 35	1956)-	1,540,000	
		2 x 55	1959)		
		TOTAL		1,980,000	
BELGIUM					
Forges de Clabecq S.A.	Ittre	2 x 65*	1964		500,000
Forges de la Providence S.A.	Marchienne-au-Pont	1 x 40*	1964		170,000
Genter Siderurgique Maritime Sidmar	Seckandi	2 x 200	1966		1,650,000
S.A. Acieries et Minieres de la Sambre	In planning stage	2 x 100*	1968		880,000
S.A. Cockerill-Ougree	Ougree-Seraing	1 x 65*	1963	200,000 (Experimental)	
		2 x 200*	1965		1,320,000
S.A. Metallurgique d'Esperance-Longdoz	Chertal	2 x 155*	1963	990,000	
Societe Metallurgique Hainaut-Sambre S.A.	Montignies-sur-Sambre	1 x 25*	1963	80,000	
		TOTAL		1,270,000	4,520,000

NOTES: * Furnaces equipped with facilities for lime powder injection through the oxygen lance.
** Furnace outputs rounded to the nearest 5 tons, annual capacities to the nearest 10,000 tons.

PX-104.

Company	Plant Location	No. of Furnaces & Output per Heat** (U.S. Short Tons)	Start-up Date	Annual Capacity** (U.S. Short Tons) Existing	Future Additions
BRAZIL					
Companhia Siderurgica Belgo-Mineira	Monlevade	2 x 40	1957	330,000	
Companhia Siderurgica Mannesmann	Belo Horisonte	2 x 30	1963	220,000	
Companhia Siderurgica Paulista - COSIPA	Piacaguera	2 x 85	1964		880,000
Siderurgica Barra Mansa S.A.	Barra Mansa	2 x 15	1963/64		140,000
Usinas Siderurgicas de Minas Gerais S.A. - USIMINAS	Ipatinga	2 x 50	1963		550,000
		TOTAL		550,000	1,570,000
CANADA					
The Algoma Steel Corp., Ltd.	Sault Ste. Marie, Ont.	2 x 105 1 x 110	1958 1963	900,000	Under Constr.
Dominion Foundries & Steel, Ltd.	Hamilton, Ont.	1 x 85) 1 x 105)	1954/56/61	1,250,000	
		TOTAL		2,150,000	-
FINLAND					
Rautaruukki Oy	Raahe	2 x 55	1965		660,000
		TOTAL			660,000
FRANCE					
Forges de la Providence S.A.	Rehon	1 x 30*	1963	120,000	
Societe des Acieries de Pompey	Pompey	1 x 20	1960	70,000	
		2 x 60	1963		400,000
		2 x 95*	1964		550,000
Societe Metallurgique de Normandie	Mondeville	2 x 65*	1960	500,000	
Union Siderurgique du Nord de la France (USINOR)	Denain Dunkerque	2 x 140* 1 x 140*	1962) 1963)	2,200,000	
		TOTAL		2,890,000	950,000
GERMANY (WEST)					
AG der Dillinger Huettenwerke	Dillingen, Saar	1 x 35* 1 x 35*	1960) 1961)	220,000	
August Thyssen-Huette AG	Duisburg-Hamborn	2 x 200	1962	1,460,000	
Bochumer Verein fuer Gussstahlfabrikation AG	Bochum	2 x 45	1957	610,000	
		2 x 165*	1963)		2,380,000
Dortmund-Hoerder Huettenunion AG	Dortmund-Hoerde	1 x 165*	1964)		
Eisenwerk-Gesellschaft Maximilianshuette mbH	Sulzbach-Rosenberg	2 x 15*	1959	110,000	
Gussstahlwerk Witten AG	Witten (Ruhr)	1 x 40	1957	110,000	
Huetten- und Bergwerke Rheinhausen AG, Huettenwerk Rheinhausen	Rheinhausen	1 x 45	1960	260,000 (Experimental)	
		2 x 95	1963)		1,980,000
		2 x 95	1965)		
Huettenwerk Salzgitter AG	Salzgitter	1 x 55*	1962	400,000	
Ilseder Huette/Peine	Peine	3 x 75*	1964		1,210,000
Mannesmann AG, Huettenwerk Huckingen	Duisburg-Huckingen	1 x 45*	1960	220,000	
		2 x 170*	1965/66		1,300,000
Phoenix-Rheinrohr AG, Vereinigte Huetten- und Rohrenwerke	Duisburg-Ruhrort	1 x 95*	1962	460,000	
		TOTAL		3,850,000	6,870,000
GREECE					
Halyvourgiki S.A.	Elevsis	2 x 35	1963		280,000
		TOTAL			280,000

Company	Plant Location	No. of Furnaces & Output per Heat** (U.S. Short Ton)	Start-up Date	Annual Capacity** (U.S. Short Tons) Existing	Future Additions
INDIA					
Hindustan Steel Ltd.	Rourkela	1 x 55	1959)	1,120,000	
		2 x 55	1960)		
Mysore Iron & Steel Ltd.	Bhadravati	2 x 65	1966		900,000
		2 x 15	1963		130,000
		TOTAL		1,120,000	1,030,000
ITALY					
ITALSIDER S.p.A.	Bagnoli	3 x 140/165	1964		2,210,000
	Taranto	2 x 285/330	1964		2,480,000
	Piombino	2 x 140/165	1965		1,380,000
		TOTAL			6,070,000
JAPAN					
Amagasaki Iron & Steel Mfg. Co., Ltd.	Amagasaki	2 x 40	1960	400,000	
Fuji Iron & Steel Co., Ltd.	Hirohata	2 x 90	1960	900,000	
	Muroran	2 x 110	1961	1,080,000	
Kawasaki Steel Corp.	Chiba	2 x 170	1962	1,650,000	
Kobe Steel Works, Ltd.	Kobe	2 x 80	1962	860,000	
Nippon Kokan Kabushiki Kaisha	Kawasaki	2 x 55	1958	570,000	
		1 x 55	1964		570,000
	Mizue	2 x 85	1960)	1,540,000	
		1 x 85	1962)		
	Tsurumi	2 x 65	1963		890,000
Nisso Steel Mfg. Co., Ltd.	Toyama	1 x 5	1961	(Experimental)	
North Japan Special Steel Co., Ltd.	Hachinohe	1 x 10	1963	60,000	
Sumitomo Metal Industries, Ltd.	Kokura	2 x 55	1961	680,000	
	Wakayama	2 x 130	1963	1,320,000	
Tokai Iron & Steel Co., Ltd. (subsidiary of Fuji Iron & Steel Co., Ltd.)	Nagoya	2 x 150	1965		1,500,000
Toohoku Electro-Chemical Industries Corp., Ltd.	Gunma	1 x 10	1960	70,000	
Yawata Iron & Steel Co., Ltd.	Kukioka	2 x 70	1957	750,000	
		1 x 75	1964		880,000
	Tobata No. 1	2 x 75	1959)	1,760,000	
		1 x 90	1960)		
	Tobata No. 2	2 x 160	1962	1,580,000	
		TOTAL		13,220,000	3,840,000
LUXEMBOURG					
Acieries Reunies de Burbach-Eich-Dudelange S.A. (ARBED)	Dudelange	1 x 30*	1958)	460,000	
		1 x 55*	1962)		
	Esch-sur-Alsette	1 x 70*			390,000
		TOTAL		460,000	390,000
NETHERLANDS					
Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V.	IJmuiden	3 x 110	1958/61†	2,000,000	
		TOTAL		2,000,000	
NORWAY					
A/S Norsk Jernverk	Mo-i-Rana	1 x 45	1961)	500,000	
		1 x 45	1962)		
		TOTAL		500,000	

NOTE: † Original furnaces (2 x 65 tons per heat) installed in 1958 were replaced by the larger furnaces in 1961.

PX-104.

Company	Plant Location	No. of Furnaces & Output per Heat** (U.S. Short Tons)	Start-up Date	Annual Capacity** (U.S. Short Tons) Existing	Future Additions
PERU					
Sociedad Siderurgica de Chimbote S.A. (SOGESA)	Chimbote	2 x 30	1963		Under Constr.
		TOTAL			—
PORTUGAL					
Siderurgia Nacional, S.A.R.L.	Seixal	2 x 45	1961	390,000	
		TOTAL		390,000	
SPAIN					
Altos Hornos de Vizcaya, S.A.	Sestao	2 x 45	1963	400,000	
Empresa Nacional Siderurgica, S.A.	Aviles	2 x 70	1963		550,000
		TOTAL		400,000	550,000
SWEDEN					
Fagersta Bruks AB	Fagersta	1 x 20 1 x 35	1958) 1962)	110,000	
		TOTAL		110,000	
TURKEY					
Eregli Demir ve Celik Fabrikalari T.A.S. (Eregli Iron & Steel Mills)	Eregli	2 x 90	1965		470,000
		TOTAL			470,000
UNITED KINGDOM					
Colvilles Ltd.	Ravenscraig Works Motherwell, Scotland	2 x 110*	1963		780,000
Consett Iron Co. Ltd.	Consett, England	2 x 110			Under Constr.
Lysaght's Scunthorpe Works (Branch of G.K.N. Steel Co. Ltd.)	Scunthorpe, England	2 x 60*	1964		500,000
Richard Thomas & Baldwins Ltd.	Ebbw Vale, Wales	1 x 40* 2 x 40	1960) 1962)	560,000	
	Spencer Works, Llanwern (nr. Newport), Wales	3 x 125	1962	1,570,000	
Stewarts & Lloyds, Ltd.	Corby, England	1 x 110* 2 x 110*	1962) 1964)		1,680,000
		TOTAL		2,130,000	2,960,000
USSR					
Bakal Metallurgicheskiy Zavod (Bakal Iron & Steel Works)	Chelyabinsk (Urals)	3 x 110	1964		2,210,000
Krivorozhstal Met. Zavod (Krivoi-Rog Steel Works)	Krivoi-Rog (Ukraine)	4 x 45 3 x 110	1958 1965	1,320,000	2,210,000
Met. Zavod Imeni Petrovskiy (Petrovsky Iron & Steel Works)	Dnepropetrovsk (Ukraine)	3 x 30	1956	550,000	
Nizhniy-Tagilskiy Met. Zavod (Nizhny-Tagil Works)	Nizhniy-Tagil (Urals)	2 x 110	1963		1,100,000
Novolipetskiy Met. Zavod (Novolipetsky Iron Works)	Novo-Lipetsk (Central European Russia)	3 x 110	1964		2,210,000
Zhdanovskiy Met. Zavod "Ilycha" ("Ilych" Tube Rolling Works)	Zhdanov (Ukraine)	3 x 110	1964		2,210,000
		TOTAL		1,870,000	9,940,000
YUGOSLAVIA					
Rudnici i Zelezara Skopje	Skopje	2 x 110	1964		660,000
		TOTAL			660,000
		TOTAL, WORLD-WIDE		46,210,000	60,910,000